PROCEEDINGS

OF

THE ROYAL SOCIETY

OF

EDINBURGH.

VOL. XII.

NOVEMBER 1882 TO JULY 1884.

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PROCEEDINGS

OF THE

ROYAL SOCIETY OF EDINBURGH.

VOL. XII. 1882–83. No. 113.

THE HUNDREDTH SESSION.

GENERAL STATUTORY MEETING.

Monday, 27th November 1882.

PROFESSOR MACLAGAN, Vice-President, in the Chair.

The following Council were elected:—

President.

THE RIGHT HON. LORD MONCREIFF.

Vice-Presidents.

Prof. DOUGLAS MACLAGAN, M.D.
Prof. H. C. FLEEMING JENKIN, F.R.S.
Rev. W. LINDSAY ALEXANDER, D.D.
J. H. BALFOUR, M.D., F.R.S.
THOMAS STEVENSON, M.In.C.E.
ROBERT GRAY, Esq.

General Secretary—Professor TAIT.

Secretaries to Ordinary Meetings.

Professor TURNER, F.R.S.
Professor CRUM BROWN, F.R.S.

Treasurer.—ADAM GILLIES SMITH, Esq., C.A.

Curator of Library and Museum—ALEXANDER BUCHAN, Esq., M.A.

Councillors.

Professor CHRYSTAL.
Sheriff FORBES IRVINE.
Professor A. DICKSON.
The Right Rev. Bishop COTTERILL.
Rev. Professor DUNS.
Dr RAMSAY TRAQUAIR.
JOHN MURRAY, Esq.
WILLIAM FERGUSON, Esq.
Professor COSSAR EWART.
Professor JAMES GEIKIE.
Rev. Dr W. ROBERTSON SMITH.
STAIR AGNEW, Esq.

By a Resolution of the Society (19th January 1880) the following Hon. Vice-Presidents, having filled the office of President, are also Members of the Council:—

HIS GRACE THE DUKE OF ARGYLL, K.T., D.C.L.
SIR WM. THOMSON, LL.D., D.C.L., F.R.S., Foreign Associate of Institute of France.

Monday, 4th December 1882.

The Right Hon. LORD MONCREIFF, President, in the Chair.

The President gave a short historical sketch of the Society on the occasion of the commencement of its Hundredth Session. He said that, before the business commenced, he ought to call attention to a peculiarity of the present meeting, and to make one or two observations upon it. This was the hundredth session of the Royal Society. Most cordially did he congratulate the Society and its members on having arrived at that interesting period of its history. But it was right he should say that it would be a mistake to suppose that, although this was the hundredth session, they were absolutely centenarian. This was not the anniversary of the birth of the Royal Society. For some reason or other—he did not know how—the hundredth session began before the Society was absolutely a hundred years old. How it exactly came about he was not quite sure. The Royal Society's charter bore date March 1783; and he supposed, like other great institutions, they had a previous autumn session—and in that way, possibly, the difference was to be accounted for. But, in any view, it is a great occasion for meditation and observation, and there may come a time for such a word, but on the present occasion he had not the material sufficient to do anything like justice to a theme so large. Only in a few sentences would he go back to March 1783, and glance upon the long career which the Society had run. A long and distinguished course, he thought they might say, seeing it was to their distinguished predecessors they owed its glory and its present flourishing existence. There had been many speculations as to where the Royal Society came from, and its feeders had been examined and searched for with great assiduity. There was a Rankinian Club in Edinburgh towards the beginning of last century, and it was claimed as the foundation of the Royal Society. Then there was a Select Society, a debating club—somewhere about 1750—where Dr Robertson and the great men of those days practised the oratory which they afterwards used with such effect; and they had been told that that to a large

extent was the origin of the Royal Society. He had looked into the Appendix to Dugald Stewart's *Life of Robertson*, and there he found a list of members of the Select Society—and it contained many, if not all, of the names of the great men who were in 1783 among its members. One distinctive thing he could gather from the notice was, that Adam Smith and David Hume were both members of it, and that neither one nor the other ever opened their lips in the Society during the time they were members of it. But he rather thought a third institution had more claim, and that was the Philosophical Society, founded by Colin Maclaurin, the great mathematician. Undoubtedly it did survive till the period when the Royal Society was formed. Colin Maclaurin, unfortunately for himself, was the engineer employed to defend Edinburgh at the time of the advance of the Pretender in 1745, and he had to leave Edinburgh. Observations had sometimes been made as if Maclaurin had made a somewhat precipitate retreat on that occasion, but the real fact was, he was the last man who left, for he found, after all the fortifications were complete, that there was nobody to man them, and no army to help in the defence. He was not the only man who had to retreat, for he rather thought the Court of Session also took that course, and before the Pretender arrived the Judges had departed to their country seats. Such was the parentage of the Royal Society. In 1783 these streams all seemed to meet, and this institution was the result. They had originally a literary side and a physical or mathematical side. At the first start they had 104 on the physical side and 114 members on the literary side. He was looking back to an address by his much valued and lamented friend Professor Forbes, which was delivered in 1862, and he would go over a few names given there as belonging to the physical side and to the literary side, and they would probably agree with him (there were many more who might go alongside of them) that it would be difficult to find in any part of Britain, or in any country out of Britain, an assemblage of persons more distinguished in their respective spheres. The physical side embraced Joseph Black, Clerk of Eldin, Lord Hailes, James Gregory, James Hutton, John Playfair, Dugald Stewart, Lord Bute, Lord Dundonald, Sir James Hall, James Watt, Dr Small (Dundee), and Patrick Wilson. And on the literary side there were

the Lord President, Chief Baron, the Lord Advocate, John Home, David Hume, Henry Mackenzie, Alexander Tytler, the Duke of Buccleuch, Archibald Alison, Dr Beattie, Edmund Burke, Lord Morton, Lord Hopetoun, John Hunter, Thomas Reid, Young of Glasgow, and Mr Liston. That was a nucleus for a great Society; and certainly from that time forward it grew and prospered until the position of a Fellow of the Royal Society of Edinburgh became one of the highest distinction. Now, it appeared, they had lasted for one hundred years. Whether they all of them could come up to the mark of the great men whose names he had read he did not know. For one thing, we knew many things they did not know, although they possibly knew a great many that we did not know; but, looking back from 1783 till now, it was a wonderful retrospect in point of knowledge and invention and progress—owing, to a large extent, to the labours of the men whose names he had just mentioned. The literary side was presided over by Sir Thomas Miller of Barskimming, who held the office of Lord Justice-Clerk, the office the speaker had the honour to hold. He was a man of very great powers—a great lawyer, and a man of very strong literary tastes. But he did not know that the literary side had quite made the progress they might have looked for during that time. It did last for about twenty years in great vigour. He had the curiosity to see what the subjects were that were treated of. There were some very vigorous papers; and among them he found a dissertation by John Maclaurin, the son of the mathematician, the object of which was to prove that Troy was not taken by the Greeks after all, which he tried to prove with a wonderful amount of learning. Perhaps he might be excused if he suggested that possibly it would be an improvement if in this respect also they followed more closely in the footsteps of their predecessors. These observations he concluded by wishing the Royal Society all prosperity in the next hundred years.

The President read the following statement in regard to the number of the Fellows of the Society :—

I. Honorary Fellows—

Royal Personage—

His Royal Highness the Prince of Wales, . 1

British Subjects at November 1881.

John Couch Adams, LL.D., Cambridge; Sir George Biddell Airy, K.C.B., Greenwich; Thos. Andrews, M.D., Belfast; Arthur Cayley, LL.D., Cambridge; Chas. Darwin, M.A., F.R.S., Kent; John Anthony Froude, LL.D., London; Sir William Robert Grove, London; Thomas Henry Huxley, LL.D., D.C.L., London; James Prescott Joule, LL.D., D.C.L., Manchester; Richard Owen, C.B., M.D., London; Thomas Romney Robinson, D.D., D.C.L., LL.D., Armagh; General Sir Edward Sabine, K.C.B., London; Rev. George Salmon, D.D., LL.D., D.C.L., Dublin; Henry John Stephen Smith, LL.D., Oxford; Balfour Stewart, LL.D., Manchester; George Gabriel Stokes, LL.D., D.C.L., Cambridge; James Joseph Sylvester, LL.D., Baltimore; Alfred Tennyson, D.C.L., Isle of Wight. Total, 18

Of these Charles Darwin and Dr T. Romney Robinson died during the Session. Deduct, 2

Total Number of British Honorary Fellows at November 1882, ... 16

Foreign Honorary Fellows at November 1881.

Robert Wilhelm Bunsen, Heidelberg; Michel Eugène Chevreul, Paris; James D. Dana, Newhaven, U.S.; Alphonse De Caudolle, Geneva; Franz Cornelius Donders, Utrecht; Jean Baptiste Dumas, Paris; Carl Gegenbaur, Heidelberg; Asa Gray, Harvard, U.S.; Hermann Ludwig Ferdinand Helmholtz, Berlin; Jules Janssen, Paris; August Kekule, Bonn; Gustav Robert Kirchhoff, Berlin; Hermann Kolbe, Leipzig; Albert

Carry forward, 17

Brought forward,		17
Kolliker, Würzburg; Ernst Eduard Kummer, Berlin; Richard Lepsius, Berlin; Ferdinand de Lesseps, Paris; Rudolph Leuckart, Leipzig; Johann Benedict Listing, Göttingen; Joseph Liouville, Paris; Sven Lovén, Stockholm; Carl Ludwig, Leipzig; J. N. Madvig, Copenhagen; Henry Milne-Edwards, Paris; Theodore Mommsen, Berlin; Simon Newcomb, Washington; Louis Pasteur, Paris; Émile Plantamour, Geneva; Carl Theodor von Siebold, Munich; Johannes Japetus Smith Steenstrup, Copenhagen; Otto Wilhelm Struve, Pulkowa; Bernard Studer, Bern; Otto Torell, Lund; Rudolph Virchow, Berlin; Wilhelm Eduard Weber, Göttingen; Friedrich Wöhler, Göttingen.		
Total number at November 1881,	36	
Of these three died during the course of last Session,—Joseph Liouville, Émile Plantamour, and Friedrich Wöhler. Deduct . .	3	
Total Number at November 1882, .		33
Total Number of British and Foreign Honorary Fellows at November 1882, .		50

II. Ordinary Fellows—

The Ordinary Fellows of the Society at November 1881 were	408
Fellows since elected—Sir Peter Coats; Andrew Young, Esq.; D. B. Dott, Esq.; Dr James Clerk Rattray; Alexander Leslie, Esq.; John Sturgeon Mackay, Esq.; Dr Henry Barnes; James Sorley, Esq.; William Thomson, Esq.; Thomas Graham Young, Esq.; W. Dyce Cay, Esq.; J. A. Dixon, Esq.; Professor C. Michie Smith; D. H. Marshall, Esq.; Josiah Livingston, Esq.; Dr David Pryde; J. W. Inglis, Esq.; Frank W. Young, Esq.; T. R. Buchanan, Esq., M.P.; Dr George Wilson; Frank E. Beddard, Esq.; Andrew Jamieson, Esq.; J. A. Wenley, Esq.	23
Carry forward,	431

	Brought forward,	431	
Deceased during Session 1881–82 — David Anderson, Esq. of Moredun; Charles D. Bell, Esq.; Dr John Brown; Sir Robert Christison, Bart.; Sir John Rose Cormack; J. Anthony Dixon, Esq.; Sheriff Frederick Hallard; James Hay, Esq.; William King, Esq.; John M'Culloch, Esq.; Sir Daniel Macnee; Dr Charles Morehead; Dr John Muir; Richard Parnell, Esq.; Samuel Raleigh, Esq.; Dr William Robertson; John Scott Russell, Esq.; Professor Spence; Sir Wyville Thomson; James Walker, Esq.; Robert Wilson, Esq.	Deduct .	21	
Total Number of Ordinary Fellows at November 1882, .			410
Total Number of Honorary Fellows at November 1882, .			50
Total Number of Fellows of the Society at November 1882,			460

Obituary Notices were read of Charles Darwin, Émile Plantamour, Charles Davidson Bell, Dr William Robertson, Sir Daniel Macnee, David Anderson, John M'Culloch, Samuel Raleigh, and Professor James Spence, deceased Fellows of the Society.

The following Communications were read:—

1. Dr Guébhard's Electro-Chemical Method of Figuring Equipotential Lines. By Rev. Dr W. R. Smith.

2. Message from the Nautical Almanac Office, in reference to the Transit of Venus, Dec. 6, 1882. Communicated by the Astronomer-Royal.

Royal Observatory, Edinburgh,
4th December 1882.

The following despatch has just been received from Mr J. R. Hind, Superintendent of the Nautical Almanac, London:—

"First external contact at 1 h. 48 m. 24 sec., mean time at Edinburgh; the place of it being at 147° N. to E. for direct image.

"First internal contact will be 21 minutes later."

The above notification indicates that the phenomena will occur 5 minutes and a few seconds later than the times printed four years ago, under difficulties, in the Nautical Almanac.

Observers should therefore be warned and prepared accordingly: viz., for 2 h. 1 m. 7 sec. in place of 1 h. 55 m. 57 sec. P.M. of Greenwich mean time as per Time-Ball and Time-Gun here in Edinburgh.

The place of first external contact will also be 2 degrees on the sun's limb nearer to its south pole, but on the east side, as before.

C. Piazzi Smyth,
Astronomer-Royal for Scotland.

To General Secretary,
Royal Society, Edinburgh.

BUSINESS.

The following Candidates were balloted for and declared duly elected Fellows of the Society:—Dr R. H. Gunning; Alexander Bruce, M.A., M.B.; Dr Charles D. F. Phillips.

Monday, 18th December 1882.

ROBERT GRAY, Esq., Vice-President, in the Chair.

The following Communications were read:—

1. On the Laws of Motion. Part I. By Professor Tait.

(*Abstract.*)

The substance of part at least of this paper was given in 1876 as an evening lecture to the British Association at its Glasgow meeting.

While engaged in writing the article "Mechanics" for the *Ency. Brit.*, I had to consider carefully what basis to adopt, and decided that the time had not yet come in which (at least in a semi-popular article) Newton's laws of motion could be modified. The article was therefore based entirely on these laws, with a mere hint towards the end that in all probability they would soon require essential modification. It is well, however, that the question of modification should now be considered; and this should be done, not in a popular essay but, before a scientific society.

The one objection to which, in modern times, that wonderfully complete and compact system is liable, is that it is expressly founded on the conception of what is now called "force" as an agent which "compels" a change of the state of rest or motion of

a body. This is part of the first law, and the second law is merely a definite statement of the amount of change produced by a given force.

(Next comes a digression as to what was Newton's expression for what we now mean by the word force, when it is used in the correct signification above.)

There can be no doubt that the proper use of the term *force* in modern science is that which is implied in the statement—Force is whatever changes a body's state of rest or motion. This is part of the first law of motion. Thus we see that force is the English equivalent of Newton's term *vis impressa.* But it is also manifest that, on many occasions, *but only where his meaning admitted of no doubt*, Newton omitted the word *impressa* and used *vis* alone, in the proper sense of force. In other cases he omitted the word *impressa*, as being implied in some other adjective such as *centripeta*, *gravitans*, &c., which he employed to qualify the word *vis.* Thus (Lemma X.) he says :—*Spatia, quæ corpus urgente quâcunque vi finitâ describit*, &c. It is needless to multiply examples. But that this is the true state of the case is made absolutely certain by the following:—

Definitio IV. Vis impressa est actio in corpus exercita, ad mutandum ejus statum vel quiescendi vel movendi uniformiter in directum.

Contrast this with the various senses in which the word *vis* is used in the comment which immediately follows, viz. :—

Constitit haec vis in actione solâ, neque post actionem permanet in corpore. Perseverat enim corpus in statu omni novo per solam vim inertiæ. Est autem vis impressa diversarum originum, ut ex ictu, ex pressione, ex vi centripetâ.

These passages are translated by Motte as below :—

"*Definition IV. An impressed force is an action exerted upon a body, in order to change its state, either of rest, or of moving uniformly forward in a right line.*"

"This force consists in the action only, and remains no longer in the body when the action is over. For a body maintains every new state it acquires, by its *vis inertiæ* only. Impressed forces are of different origins ; as from percussion, from pressure, from centripetal force."

The difficulty which Motte here makes for himself, and which he escapes from only by leaving part of the passage in the original Latin, is introduced solely by his use of the word *force* as the equivalent of the Latin *vis.*

If we paraphrase the passage as follows, with attention to Newton's obvious meaning, this difficulty disappears, or rather does not occur:—

"This kind of vis consists in," &c. For the "body continues . . . . by the vis of inertia," &c. However, we may quote two other passages of Newton bearing definitely on this point.

Definitio III. Materiæ vis insita est potentia resistendi, quâ corpus unumquodque, quantum in se est, perseverat in statu suo vel quiescendi vel movendi uniformiter in directum.

It is perfectly clear that, in this passage, the phrase *vis insita* is one idea, not two, and that *vis* cannot here be translated by *force.* Yet Motte has

"The *vis insita*, or innate force of matter, is," &c.

Definitio V. Vis centripeta est, quâ corpora versus punctum aliquod, tanquam ad centrum, undique trahuntur, impelluntur, vel utcumque tendunt.

It is obvious that the qualifying term *centripeta* here includes the idea suggested by *impressa*, defining in fact the direction of the *vis*, and therefore implying that its origin is outside the body.

After what has just been said, no farther comment need be added to show the absurdity of the terms *accelerating force*, *innate force*, *impressed force*, &c. All of these have arisen simply from mistranslation. Vis, by itself, is often used for force; but *vis acceleratrix*, *vis impressa*, *vis insita*, and other phrases of the kind, must be taken as wholes; and, in them, *vis* does not mean *force.*

The absurdity of translating the word *vis* by *force* comes out still more clearly when we think of the term *vis viva*, or *living force* as it is sometimes called; a name for kinetic energy, which depends on the unit of length in a different way from force. It must be looked upon as one of the most extraordinary instances of Newton's clearness of insight that, at a time when the very terminology of science was only as it were shaping itself, he laid down with such wonderful precision a system absolutely self-consistent.

From the passages just quoted, taken in conjunction with the

second law of motion, we see that (as above stated) in Newton's view—

Force is whatever causes (but not, *or tends to cause*) *a change in a body's state of rest or motion.*

Newton gives no sanction to the so-called *statical* ideas of force. Every force, in his view, produces its effect. The effects may be such as to balance or compensate one another; but there is no balancing of forces.

(Next comes a discussion as to the objectivity or subjectivity of force. An abstract of this is given in §§ 288–296 of the article above referred to, and therefore need not be reproduced here.)

But, just as there can be no doubt that force has no objective existence, so there can be no doubt that the introduction of this conception enabled Newton to put his *Axiomata* in their exceedingly simple form. And there would be, even now, no really valid objection to Newton's system (with all its exquisite simplicity and convenience) could we only substitute for the words "force" and "action," &c., in the statement of his laws, words which (like rate or gradient, &c.) do not imply objectivity or causation in the idea expressed. It is not easy to see how such words could be introduced; but assuredly they will be required if Newton's system is to be maintained. The word stress might, even yet, be introduced for this purpose; though, like force, it has come to be regarded as something objective. Were this possible, we might avoid the necessity for any very serious change in the *form* of Newton's system. I intend, on another occasion, to consider this question. How complete Newton's statement is, is most easily seen by considering the so-called "additions" which have been made to it.

The second and third laws, together with the scholium to the latter, expressly include the whole system of "effective forces," &c. for which D'Alembert even now receives in many quarters such extraordinarily exaggerated credit. The "reversed effective force" on a particle revolving uniformly in a circle is nothing but an old friend—"centrifugal force." And even this phantom is still of use, *in skilled hands,* in forming the equations for certain cases of motion.

The chief arguments for and against a modern modification of the laws of motion are therefore as follows—where we must remember that they refer exclusively to the elementary teaching of the subject,

and have no application to the case of those who have sufficient knowledge to enable them to avoid the possible dangers of Newton's method :—

I. For. Is it wise to teach a student by means of the conception of force, and then as it were to kick down the scaffolding by telling him there is no such thing?

II. Against. Is it wise to give up the use of a system, due to such an altogether exceptional genius as that of Newton, and which amply suffices for all practical purposes, merely because it owes part of its simplicity and compactness to the introduction of a conception which, though strongly impressed on us by our muscular sense, corresponds to nothing objective?

Everyone must answer these questions for himself, and his answer will probably be determined quite as much by his notions of the usefulness of the study of natural philosophy as by his own idiosyncrasies of thought. To some men physics is an abomination, to others it is something too trivial for the human intellect to waste its energies on. With these we do not reason. To others again all its principles are subjects of intuitive perception. *They* could have foreseen the nature of the physical world, and they *know* that it could not have been otherwise than they suppose it to be. Many minds find delight in the contemplation of the three kinds of lever; others in the ingeniously disguised assumptions in Duchayla's "proof" of the parallelogram of forces; some, perhaps, even in the wonderful pages of *Vis Inertiæ Victa!* The case of these men is only not more hopeless than that of the former classes because it is impossible that it could be so.

But those who desire that their scientific code should be, as far as possible, representative of our real knowledge of objective things, would undoubtedly prefer to that of Newton a system in which there is not an attempt, however successful, to gain simplicity by the introduction of subjective impressions and the corresponding conceptions.

In the present paper simplicity of *principle*, only, is sought for; and the mathematical methods employed are those which appeared (independent altogether of the question of their fitness for a beginner) the shortest and most direct. A second part will be devoted to simplicity of *method* for elementary teaching.

(1) So far as our modern knowledge goes there are but two objective things in the physical world—matter and energy. Energy cannot exist except as associated with matter, and it can be perceived and measured by us only when it is being transferred, by a "dynamical transaction," from one portion of matter to another. In such transferences it is often "transformed"; but no process has ever been devised or observed by which the quantity, either of matter or energy, has been altered.

(2) Hence the true bases of our subject, so far as we yet know, are—

1. Conservation of matter.
2. Conservation of energy.
3. That property (those properties ?) of matter, in virtue of which it is the necessary vehicle, or as the case may be, the storehouse, of energy.

(3) The third of these alone presents any difficulty. So long as energy is obviously kinetic, this property is merely our old friend *inertia.* But the mutual potential energy of two gravitating masses, two electrified bodies, two currents, or two magnets, is certainly associated (at least in part, and in some as yet unknown way) with matter, of a kind not yet subjected to chemical scrutiny, which occupies the region in which these masses, &c., are situated. And, even when the potential energy obviously depends on the strain of a portion of ordinary matter, as in compressed air, a bent spring, a deformed elastic solid, &c., we can, even now, only describe it as due to "molecular action," depending on mechanism of a kind as yet unknown to us, though, in some cases, at least partially guessed at.

(4) The necessity for the explicit assumption of the third principle, and a hint at least of the limits within which it must be extended, appear when we consider the very simplest case of motion, viz., that of a lone particle moving in a region in which its potential energy is the same at every point. For the conservation of energy tells us merely that its *speed* is unaltered. We know, however, that this is only part of the truth: the *velocity* is constant. It will be seen later that this has most important dynamical consequences in various directions.

(The remarkable discussion of this point by Clerk-Maxwell is then referred to, in which it is virtually shown that, were things other-

wise, it would be possible for a human mind to have knowledge of *absolute* position and of *absolute* velocity.)

(5) But Maxwell's reasoning is easily seen to apply equally to any component of the velocity. Hence, when we come to the case in which the potential energy depends on the position, the only change in the particle's motion at any instant is a change of the speed in the normal to the equipotential surface on which the particle is at that instant situated. The conservation of energy assigns the amount of this change, and thus the motion is completely determined. In fact, if x be perpendicular to the equipotential surface, the equation

$$\tfrac{1}{2}m(\dot{x}^2+\dot{y}^2+\dot{z}^2)+\mathrm{V}=\text{const},$$

gives

$$m\ddot{x}=-\frac{d\mathrm{V}}{dx},$$

for $\dot{y}$ and $\dot{z}$ are independent of x. Generally, in the more expressive language of quaternions,

$$m\ddot{\rho}=-\nabla\mathrm{V}.$$

In fact, this problem is precisely the same as was that of the motion of a luminous corpuscle in a non-homogeneous medium, the speed of passing through any point of the medium being assigned.

(6) It is next shown that the above inertia-condition (that the velocity parallel to the equipotential surface is the same for two successive elements of the path) at once leads to a "stationary" value of the sum of the quantities *vds* for each two successive elements, and therefore for any finite arc, of the path. This is, for a single particle, the *Principle of Least Action*, which is thus seen to be a direct consequence of inertia.

(It is then shown that the results above can be easily extended to a particle which has two degrees of freedom only.)

But it is necessary to remember that, in these cases, we take a partial view of the circumstances; for a lone particle cannot strictly be said to have potential energy, nor can we conceive of a constraint which does not depend upon matter other than that which is constrained. Hence the true statement of such cases requires further investigation.

(7) To pass to the case of a system of free particles we require

some quasi-kinematical preliminaries. These are summed up in the following self-evident proposition :—If with each particle of a system we asssciate two vectors, *e.g.*, Θ_1, Φ_1, with the mass m_1, &c., we have

$$\Sigma m\Theta\Phi = \Sigma(m) \,.\, \Theta_0\Phi_0 + \Sigma m\theta\phi,$$

where

$$\Theta = \Theta_0 + \theta,$$
$$\Phi = \Phi_0 + \phi,$$

and

$$\Sigma m\Theta = \Sigma(m) \,.\, \Theta_0$$
$$\Sigma m\Phi = \Sigma(m) \,.\, \Phi_0,$$

so that Θ_0 and Φ_0 are the values of Θ and Φ for the whole mass collected at its centre of inertia; and θ, ϕ, those of the separate particles relative to that centre.

(8) Thus, if $\Theta = \mathrm{P} = \mathrm{P}_0 + \rho$ be the vector of m, $\Phi = \dot{\Theta} = \dot{\mathrm{P}} = \dot{\mathrm{P}}_0 + \dot{\rho}$, its velocity, we have

$$\Sigma m\mathrm{P}\dot{\mathrm{P}} = \Sigma(m) \,.\, \mathrm{P}_0\dot{\mathrm{P}}_0 + \Sigma m\rho\dot{\rho}$$

the scalar of which is, in a differentiated form, a well-known property of the centre of inertia. The vector part shows that the sum of the moments of momentum about any axis is equal to that of the whole mass collected at its centre of inertia, together with those of the several particles about a parallel axis through the centre of inertia.

If

$$\Theta = \Phi = \dot{\mathrm{P}},$$

we have

$$\Sigma m\dot{\mathrm{P}}^2 = \Sigma(m) \,.\, \dot{\mathrm{P}}_0^2 + \Sigma m\dot{\rho}^2,$$

i.e., the kinetic energy, referred to any point, is equal to that of the mass collected at its centre of inertia, together with that of the separate particles relative to the centre of inertia.

If we integrate this expression, multiplied by dt, between any limits, we obtain a similar theorem with regard to the action of the system.

Such theorems may be multiplied indefinitely.

(9) From those just given, however, if we take them along with 3 above, we see at once that, provided the particles of the system be all free, while the energy of each is purely kinetic and independent alike of the configuration of the system and of its position in space,

1. The centre of inertia has constant velocity.

2. The vector moment of momentum about it is constant.

3. So is that of the system relative to any uniformly moving point.

4. $\Sigma\int mvds$ is obviously a minimum.

(10) The result of (7) points to an independence between two parts of the motion of a system, *i.e.*, that relative to the centre of inertia, and that of the whole mass supposed concentrated at the centre of inertia. Maxwell's reasoning is applicable directly to the latter, if the system be self-contained, *i.e.*, if it do not receive energy from, or part with it to, external bodies. Hence we may extend the axiom 3 to the centre of inertia of any such self-contained system, and, as will presently be shown, also to the motion of the system relative to its centre of inertia. This, though not *formally* identical with Newton's Lex III., leads, as we shall see, to exactly the same consequences.

(11) If, for a moment, we confine our attention to a free system consisting of two particles only, we have

$$m_1\dot{\rho}_1 + m_2\dot{\rho}_2 = (m_1 + m_2)\alpha,$$

or

$$m_1\ddot{\rho}_1 + m_2\ddot{\rho}_2 = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

This must be consistent with the conservation of energy, which gives

$$\tfrac{1}{2}(m_1\dot{\rho}_1^2 + m_2\dot{\rho}_2^2) = f(\mathrm{T}(\rho_1 - \rho_2)) \quad . \quad . \quad . \quad . \quad . \quad (2)$$

since the potential energy must depend (so far as *position* goes) on the distance between the particles only. Comparing (1) and (2) we see that we may treat (2) by partial differentiation, so far as the coördinates of m_1 and m_2 are separately concerned. For we thus obtain

$$m_1\ddot{\rho}_1 = \nabla_{\rho_1} \cdot f = f' . \mathrm{U}(\rho_1 - \rho_2)$$
$$m_2\ddot{\rho}_2 = \nabla_{\rho_2} \cdot f = -f' . \mathrm{U}(\rho_1 - \rho_2).$$

Each of these, again, is separately consistent with the equation in § (5) for a lone particle. Hence, again, the integral $\int(m_1v_1ds_1 + m_2v_2ds_2)$ has a stationary value.

Hence also, whatever be the origin, provided its velocity be constant,

$$\Sigma m\mathrm{V}\rho\ddot{\rho} = 0.$$

Thus, even when there is a transformation of the energy of the system, the results of § 9 still hold good. And it is to be observed that if one of the masses, say m_2, is enormously greater than the other, the equation

$$m_1\ddot{p}_1 + m_2\ddot{p}_2 = 0$$

shows that $\ddot{p}_2$ is excessively small, and the visible change of motion is confined to the smaller mass. Carrying this to the limit, we have the case of motion about a (so-called) "fixed centre." In such a case it is clear that though the *momenta* of the two masses relative to their centre of inertia are equal and opposite, the kinetic energy of the greater mass vanishes in comparison with that of the smaller.

These results are then extended to any self-contained system of free particles, and the principle of *Varying Action* follows at once. It is thus seen to be a general expression of the three propositions of § 2 above.

(12) So far as we have yet gone, nothing has been said as to *how* the mutual potential energy of two particles depends on their distance apart. If we suppose it to be enormously increased by a very small increase of distance, we have practically the case of two particles connected by an inextensible string—as a chain-shot. But from this point of view such cases, like those of connection by an extensible string, fall under the previous categories.

The case of impact of two particles falls under the same rules, so far as motion of the centre of inertia, and moment of momentum about that centre, are concerned. The conservation of energy, in such cases, requires the consideration of the energy spent in permanently disfiguring the impinging bodies, setting them into internal vibration, or heating them. But the first and third of these, at least, are beyond the scope of abstract dynamics.

(13) The same may be said of constraint by a curve or surface, and of loss of energy by friction or resistance of a medium. Thus a constraining curve or surface must be looked upon (like all physical bodies) as deformable, but, if necessary, such that a very small deformation corresponds to a very great expenditure of energy.

(14) To deal with communications of energy from bodies outside the system, all we need do is to *include them in the system.* Treat as before the whole system thus increased, and then consider only

the motion of the original parts of the system. This method applies with perfect generality whether the external masses be themselves free, constrained, or resisted.

(15) Another method of applying the same principles is then given. Starting from the *definition* $dA = \Sigma m S \rho d\rho$, the kinematical properties of A are developed. Then, by the help of § 2, these are exhibited in their physical translations.

(16) The paper concludes with a brief comparison of the fundamental principles of the science as they have been introduced by Newton, Lagrange, Hamilton, Peirce, Kirchhoff, and Clerk-Maxwell, respectively; and also as they appear in the unique Vortex-system of Thomson.

2. On Illegitimacy in Scotland. By Mr Geo. Seton, M.A. Oxon.

In the year 1860, at the meeting of the Social Science Association in Glasgow, I read a paper on "The *Causes* of Illegitimacy in Scotland," which was published shortly afterwards; and eleven years later (1871), at the meeting of the British Association in Edinburgh, I read another paper on "The Illegitimacy of Banffshire," which was privately printed. On the present occasion I intend to confine my observations to the *facts* exhibited by the Registrar-General's returns.

For a good many years a perceptible improvement has been going on in England in the matter of illegitimacy; and I am glad to be able to add that in Scotland also we have evidence of a gradual, and nearly as satisfactory, diminution in the number of illegitimate births. During the two decades, ending 1870 and 1880 respectively, the decrease in England was rather more, and in Scotland rather less, than 1 per cent.

Percentage of Illegitimacy.

	1861–70.	1871–80.	Decrease.
England, ...	6·1	5·0	1·1
Scotland, ...	9·7	8·8	0·9

From the Forty-second Annual Report of the English Registrar-

General it appears that, during the thirty-four years ending 1879, the proportion of illegitimate children to every 100 births gradually fell from 6·7 to 4·7 per cent., or exactly 2 per cent., as shown in the following table :—

ENGLAND.

Children Born out of Wedlock to 100 Births.

1846–50,	6·7
1851–55,	6·6
1856–60,	6·5
1861–65,	6·4
1866–70,	5·8
1871–75,	5·2
1876–79,	4·7

As in Scotland, the rates have always greatly varied in different counties. While the average for the whole of England during the ten years ending 1879 was 5·1 per cent., that for Cumberland was as high as 8·9—little more, however, than half the percentage for Banffshire, and only a fraction above the average for Scotland. In the extra-metropolitan portion of Middlesex the percentage was as low as 3·6. With regard to illegitimacy, England may be roughly divided into three zones :—(1) a southern zone with the rate below the average ; (2) a midland zone with the rate somewhat above the average ; and (3) a northern zone with an excessively high rate. Perhaps, therefore, our English neighbours will feel disposed to suggest that the proximity of the northern counties to Scotland may have something to do with their high rate of illegitimacy.* Both the English and Scottish returns show that in the great centres of population the percentage of illegitimacy is much smaller than in the rural districts. It must, however, be constantly borne in mind that a comparison of the numbers of illegitimate births in town and

* It has been frequently alleged that under the Scottish system of registration the illegitimate births are more accurately recorded than in England ; and that if the respective returns were equally trustworthy, the difference in the ratio of illegitimacy on the two sides of the Tweed would not be so great as it has hitherto appeared. I am disposed to think that there is some truth in the assertion. Roughly speaking, the percentage of illegitimacy in England and Scotland, as indicated by the returns, is at present about 5 and 9 respectively. Probably 7 and 9 per cent. is nearer the actual fact. The object of this paper, however, is not to compare the two countries, but to show the vast differences in the percentage of illegitimacy which present themselves in the various counties of Scotland.

country districts respectively is not in itself sufficient to afford any indication of the true state of morality. Every statist is aware that the unrestrained passions which in rural districts result in illegitimate births are in large towns diverted into the channel of barren prostitution. The English Registrar-General remarks that, "it is probable that a considerable portion of illegitimate children are the offspring of country girls who have gone into domestic service in towns, and have there been seduced; and such girls will often return to the country for their confinement, and thus increase the country rate of illegitimacy by the addition of births which from their origin should duly be reckoned as belonging to the towns." On the other hand, however, it is quite as likely that a good many mothers of illegitimate children conceived in rural districts resort to private lodgings or maternity hospitals in large towns for the purpose of being confined.

In Scotland, during the two decades ending 1870 and 1880 respectively, there had been a diminution in the rate of illegitimacy to the extent of nearly 1 per cent., viz., 8·8 instead of 9·7. If a wavy line be drawn from Portskerry, about twelve miles west of Thurso, to Fort-George, and thence, by the eastern boundaries of Inverness, Argyll, Stirling, Lanark, and Ayr, to the mouth of Loch Ryan, it will be found that all the counties to the west of the line present a percentage of illegitimacy below the ratio for the whole of Scotland; while two-thirds of the counties to the east of the line present a percentage above that ratio—the majority of the others yielding a percentage closely bordering on the national rate. There were thus ten counties on the west of the line in question below the national ratio; while of the twenty-one counties on the east of the line, fourteen ranged from 9·0 (Nairn) to 16·6 (Banff), and the remaining seven from 7·3 (Fife) to 8·7 (Selkirk). One of these seven (Edinburgh) contains a large city, while three others (Fife, Clackmannan, and Selkirk) embrace towns of considerable size, thereby probably accounting, by the barren prostitution of large centres, for the comparatively small number of illegitimate births. The insular counties (Orkney and Shetland) were considerably below the national average—having respectively 6·0 and 4·8 per cent.

In 1881 the population of the Western area amounted to 1,859,000, and of the Eastern area to 1,814,000—a difference of

only 45,000. By far the larger portion of the Western area is occupied by an almost purely Celtic population; while the inhabitants of the Eastern area, with the exception of the county of Perth, are chiefly Scandinavian or Teutonic.

In three of the eleven counties constituting the northern division of Scotland,—viz., Nairn, Aberdeen, and Kincardine,—and in all the counties south of Banffshire, with the exception of four,—amounting in all to twenty,—the decrease in the rate of illegitimacy ranged from 0·5 per cent. in the case of Roxburgh, to 1·9 per cent. in the case of Clackmannan. On the other hand, in eight of the eleven northern counties, and also in Argyll, Linlithgow, Dumfries, and Kirkcudbright—in all twelve counties—there had been an increase in the rate, ranging from 0·1 per cent. in Ross and Cromarty, and Dumfries, to no less than 2·2 per cent. in Caithness. In both decades Banffshire retained the discreditable distinction of being at the top of the list, showing the slight increase of 0·4 per cent. (16·6 instead of 16·2)—in other words, one illegitimate child in every six births, or nearly double the percentage for the whole of Scotland. One county (Wigtown) was stationary at 16·1 per cent. The two blackest spots have always been three adjoining counties in the north (Elgin, Banff, and Aberdeen), and three adjoining southern counties (Wigtown, Kirkcudbright, and Dumfries), the collective percentage of the two groups being almost identical.

In the case of rather more than one-fourth of the whole illegitimate births the paternity was acknowledged at registration; in a good many instances the paternity was subsequently found by decree of court and recorded in terms of the statute; while about 3 per cent. of the children were legitimated by the subsequent marriage of their parents.*

* During the four years ending 1861, of the 7517 births registered in Banffshire, 1189 were illegitimate. In the case of 389 of these children—or nearly a third of the whole—the paternity was acknowledged at registration; in 64 instances the paternity was subsequently found by decree of court and recorded in terms of the statute; and in 28 cases the children were legitimated *per subsequens matrimonium*, such alteration of statu being also duly registered. In a few instances the judicial findings relate to children whose paternity was acknowledged at registration, from which it would appear that, notwithstanding the reputed father's adhibition of his signature to the register, the mother is occasionally induced to raise an action against him. Of course the paternity of some more of the "fatherless"

PERCENTAGE OF ILLEGITIMACY IN SCOTLAND AND ITS COUNTIES.

	1861–70.	1871–80.	Increase or Decrease.
SCOTLAND,	9·7	8·8	−0·9
COUNTIES.			
NORTHERN.			
Shetland,	4·2	4·8	+0·6
Orkney,	5·0	6·0	+1·0
Caithness,	8·7	10·9	+2·2
Sutherland,	5·8	6·9	+1·1
NORTH-WESTERN.			
Ross and Cromarty,	4·5	4·6	+0·1
Inverness,	8·0	8·3	+0·3
NORTH-EASTERN.			
Nairn,	10·7	9·0	−1·7
Elgin,	14·0	15·7	+1·7
Banff,	16·2	16·6	+0·4
Aberdeen,	15·2	14·3	−0·9
Kincardine,	14·4	13·3	−1·1
EAST MIDLAND.			
Forfar,	11·9	10·5	−1·4
Perth,	11·0	9·8	−1·2
Fife,	8·1	7·3	−0·8
Kinross,	11·2	10·3	−0·9
Clackmannan,	9·9	8·0	−1·9
WEST MIDLAND.			
Stirling,	8·4	7·0	−1·4
Dumbarton,	7·4	5·8	−1·6
Argyll,	7·3	7·8	+0·5
Bute,	8·0	7·4	−0·6
SOUTH-WESTERN.			
Renfrew,	7·4	6·2	−1·2
Ayr,	9·1	8·0	−1·1
Lanark,	8·4	7·3	−1·1
SOUTH-EASTERN.			
Linlithgow,	7·9	8·3	+0·4
Edinburgh,	9·1	7·8	−1·3
Haddington,	9·5	8·2	−1·3
Berwick,	10·9	10·3	−0·6
Peebles,	9·9	8·5	−1·4
Selkirk,	9·3	8·7	−0·6
SOUTHERN.			
Roxburgh,	11·5	11·0	−0·5
Dumfries,	14·9	15·0	+0·1
Kirkcudbright,	15·0	15·2	+0·2
Wigtown,	16·1	16·1	0·0

In his report relative to the year 1880, Mr Daniel Stewart, the intelligent examiner of registers in the southern district of Scotland, gives some very startling information regarding the illegitimacy of the counties of Roxburgh, Dumfries, Kirkcudbright, and Wigtown. In no fewer than 33 parishes in these four counties, the illegitimate births amounted to 20 per cent. and upwards—a certain small parish in Roxburghshire exhibiting the enormous ratio of 36·3 per cent.! He refers to the large number of cases in which *sisters* give birth to illegitimate children, and to the numerous instances of the same woman being the mother of several children. Thus, in each of twelve specified parishes, two sisters registered illegitimate births during 1880. These 24 women had given birth to 41 children. In the case of twelve of them it was the first child, while the remaining twelve had collectively produced 29 children. In each of three parishes in three of the counties in question, *three* sisters have had nine children among them, while a trio in a certain Berwickshire parish have had at least ten. In nine parishes, mothers recorded their fifth, and in five parishes, their sixth child; most of them being either domestic servants or engaged in some kind of agricultural labour. In two cases, in the counties of Kirkcudbright and Selkirk respectively, a charwoman and a dressmaker each recorded their seventh child. To only a small extent is the illegitimacy of the counties in question to be accounted for by the prevalence of concubinage.

The result of Mr Stewart's inquiries seems to point irresistibly to "a wide-spread low moral tone among domestic and farm servants in rural parishes," and mainly to that cause he is disposed to attribute the large proportion of illegitimate births constantly occurring in the southern counties. Many registrars have told him that "language of the most immoral kind is quite common among out-workers and other women engaged in farm work; and when they have once fallen they appear to lose all sense of shame and self-respect."

Note.—Mr Stewart's report for 1881 (which has been received since this paper was written) furnishes further evidence of the pre-

majority may yet be judicially established, and other cases of legitimation by the subsequent marriage of the parents may also take place; but no very material addition is likely to be made to the figures specified.

valence of illegitimacy, especially in the four counties already referred to. The following table exhibits some very startling facts :—

SOUTHERN DISTRICT—1881.

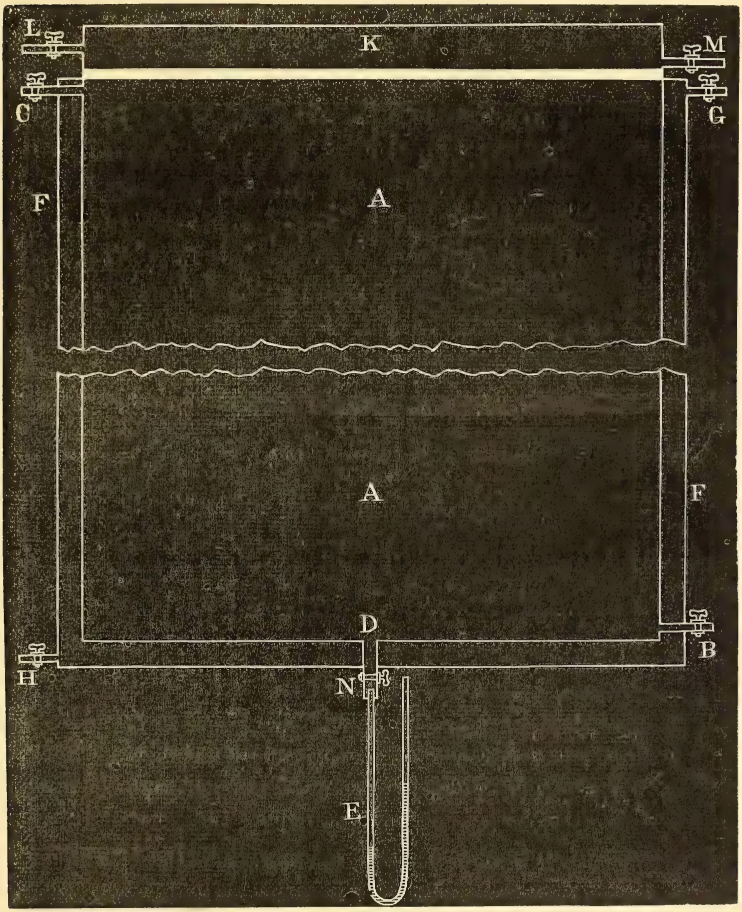
County.	Number of Illegitimate Births.	Percentage of Illegitimates.	Number of Child of Mother.									Total Number of Women Confined before.	Total Number of Children among them.
			2nd.	3rd.	4th.	5th.	6th.	7th.	8th.	9th.	10th.		
Roxburgh,	170	10·4	11	9	4	...	1	...	...	...	...	25	71
Dumfries,	349	14·8	28	11	1	5	1	...	1	...	...	47	132
Kirkcudbright,	157	12·4	9	6	2	...	1	2	...	...	...	20	64
Wigtown,	182	15·3	9	10	2	2	1	...	1	...	1	26	90
	858	...	57	36	9	7	4	2	2	...	1	118	357

In a small Dumfriesshire parish a domestic servant, who recorded her third (or fourth) illegitimate child, has three sisters, each of whom has given birth to three bastard children—"who make a trade of the offence" (in the words of the local registrar), "as they afterwards go out as nurses." In another parish in the same county, the percentage of illegitimacy had reached the alarming ratio of 40·7 per cent.! In the county of Wigtown there was not a single parish without illegitimate births, and only in two parishes was the rate below the national average. In the other 15 parishes, the percentage ranges from 9·6 to 24·1. Numerous instances of *hereditary* illegitimacy occur in the southern counties—many women (themselves illegitimate) and their daughters recording bastards in the same register.

3. On the Absorption of Low Radiant Heat by Gaseous Bodies. By Professor MacGregor.

The following pages contain an account of experiments made by myself and Mr T. Lindsay, at the request of Professor Tait, to determine the absorption of damp air containing a known quantity of water vapour, by finding in what proportions dry air and olefiant gas must be mixed in order that the absorption of the mixture may be the same as that of the damp air. The experiments were made

according to the method described by Professor Tait in a letter read by Sir William Thomson at the Southampton meeting of the British Association (see *Nature*, vol. xxvi. p. 639, 1882). They consist of two series—the first, a series of rough experiments made, first, to



determine whether or not the method would work, and, secondly, to find the dimensions of the apparatus which would give the best result; the second, a series of more careful experiments made when the method was found to give satisfactory results.

The apparatus which we used for the preliminary experiments is shown in diagrammatic section in the figure. It consisted of a cylindrical gas reservoir (A, A) of tinned iron, about 4 feet in length and 4·5 inches in diameter. This reservoir may be called the absorber. It was placed with its axis vertical. It had three openings B, C, D, of which the two (B and C) were fitted with metal tubes and stopcocks, and were used for filling the reservoir with the gas under investigation, and the third (D) was fitted with a metal tube holding the manometer E. The curved surface and the bottom of the absorber were surrounded by another cylindrical vessel F, F, also of tinned iron, whose sides were everywhere about 0·5 inch from the sides of the absorber. This outer casing had two openings (G, H) fitted with tubes and stopcocks, the one at the bottom, the other at the top. By their means the space between A and F could be kept full of running water. On the upper end of the absorber was a flat cylindrical box (K) about 1 inch in depth. The upper end of the cylinder formed the bottom of the box. This box, which may be called the radiator, was also provided with two stopcocks and tubes L, M, placed as in the diagram, by means of which it could be filled with either water or steam. For this purpose an india-rubber tube from M dipped under water in a sink, while L could be put in communication by means of a three-way tube with either a boiler or the water supply. The absorber was thus completely surrounded by a jacket divided into two compartments, one of which was the radiator. The manometer E consisted of a bent tube of about 1^{mm} bore. It was provided with a stopcock N, was fitted in the tube D by means of an india-rubber stopper, and contained dilute sulphuric acid of known density. The levels of the liquid were read off by the aid of a card, with a divided scale, which was attached to the tube.

The following is a description of our mode of observation. The absorber was first filled with the gas under investigation. Thus, to fill with dry air, B was attached to a series of drying tubes (sulphuric acid and chloride of calcium) and C to the suction pump, and a current was kept up until the dry air had displaced the damp air which at first filled A. To fill with moist air, the drying tubes were replaced by wetting tubes. To fill with olefiant gas, C was left open, and the gas driven in from the generator at B until the

air initially filling A had been displaced. Meantime water had been kept running through both compartments of the jacket. The water from the laboratory reservoir was found to be practically invariable in temperature during the course of any one experiment. When the absorber had been filled, and the water had been running through the jacket for some time, the stopcocks B and C were closed and D opened. The water was then kept running through the jacket until the gas in the absorber had attained a practically constant temperature, until the liquid in the manometer therefore indicated a practically constant pressure. The barometer and manometer were then read, and the temperature of the water jacket noted. Then L was put in communication with the boiler, and the water in the radiator was displaced by steam, after which the variation of the manometer with time was noted until it had again reached a constant state, when the barometer was again read. If the readings of the barometer before and after any set of observations were not the same, it was supposed to have varied uniformly with time in calculating pressures. In all cases the difference was very slight, the sets of observations lasting only from 20 to 30 minutes. From the readings of the barometer and manometer the pressures were easily calculated.

No precautions were taken specially to exclude dust, so that, when water was present in the gas operated on, it was not necessarily all in the state of vapour.

The following are details of some of the experiments made. The unit employed in the measurement of pressure is that due to a millimetre of the dilute acid solution used in the manometer. Its density was 1·1038. Zero of time is the moment at which communication was broken between the radiator K and the water supply, and established between the radiator and the boiler. Shortly after that the upper end of the absorber begins to rise in temperature, and the pressure of the gas contained in it to increase. When the steam issues freely from the radiator, it may be supposed to have very nearly reached a constant temperature.

I. *Dry Air.*—Air had been drawn from the drying tubes through the absorber for 2 hours. The following table shows the pressures after given intervals of time :—

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9316·9	4	15	9344·7
0	20	9319·7	5	30	9346·7
0	30	9325·7	6	20	9347·7
0	37	9335·7	7	30	9348·7
0	45	Steam issuing freely.	9	33	9350·7
			10	52	9351·7
0	56	9337·7	12	32	9352·7
1	17	9339·7	13	47	9353·9
1	43	9340·7	15	17	9354·7
2	15	9341·7	18	17	9356·7
3	0	9342·7	20	52	9357·7
3	45	9343·7			

II. *Damp Air.*—Air had been drawn through the absorber for 15 minutes, after having passed through a Woulfe's bottle of water.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9311·2	1	8	9331·7
0	15	9311·7	1	55	9332·2
0	20	9319·7	3	6	9332·7
0	26	9325·7	5	10	9334·7
0	31	9330·7	6	0	9335·7
0	37	Steam issuing freely.	9	15	9337·7
			10	30	9338·7
0	54	9331·2	14	5	9340·7

III. *Damp Air.*—The air had for 2 hours been drawn through the absorber, after passing through a Woulfe's bottle containing water.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9314·6	0	45	9336·6
0	15	9316·6	1	15	9336·6
0	22	9328·6	2	25	9336·6
0	27	9333·6	3	55	9337·1
0	35	9335·6	4	25	9337·6
0	36	Steam issuing freely.	5	25	9338·1
			12	0	9338·1

IV. *Damp Air.*—The same air as in No. III.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9314·1	2	30	9333·6
0	27	9323·6	3	45	9334·1
0	32	9328·6	4	20	9334·6
0	40	9332·6	5	30	9335·6
0	41	Steam issuing freely.	7	45	9337·1
			8	45	9337·6
1	6	9333·1	13	45	9338·1
1	35	9333·5	15	0	9338·1

V. *Dry Air.*—The air had been drawn through the absorber and drying tubes for 3½ hours.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9334·9	2	0	9356·4
0	24	9336·4	2	15	9357·4
0	32	9338·4	2	35	9358·4
0	40	9341·4	3	25	9359·4
0	45	9343·4	4	45	9362·4
0	50	9346·4	5	15	9363·4
0	57	9348·4	6	20	9364·4
1	5	9351·4	7	45	9368·4
1	6	Steam issuing freely.	9	35	9370·4
			11	12	9372·4
1	20	9354·4	12	54	9373·4
1	30	9355·4	16	0	9375·4

VI. *Dry Air.*—The same air as in No. V.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9326·4	2	30	9350·4
0	20	9336·4	3	0	9351·4
0	25	9342·4	3	25	9352·4
0	30	9346·4	3	45	9353·4
0	36	9348·4	5	0	9356·4
0	36	Steam issuing freely.	5	25	9357·4
			6	20	9358·4
0	46	9349·4	8	40	9362·4
1	5	29349·6	12	15	9364·4

VII. *Dry Air.*—Air was again drawn through the drying tubes and absorber for one hour.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9334·9	1	4	9358·9
0	18	9343·4	1	46	9359·4
0	23	9348·4	2	20	9361·4
0	28	9353·4	3	25	9363·4
0	34	9356·4	4	45	9367·4
0	34	Steam issuing freely.	6	30	9372·4
0	43	9358·4	8	20	9375·4

VIII. *Damp Air.*—The air was drawn through the wetting tubes and the absorber for 2·75 hours.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9333·8	3	0	9354·8
0	20	9343·8	4	15	9356·8
0	29	9350·8	5	10	9357·8
0	34	9351·8	5	55	9358·8
0	34	Steam issuing freely.	7	55	9361·3
			8	35	9361·8
0	45	9352·6	11	0	9362·8
1	28	9353·3	13	25	9363·8
2	25	9353·8	19	0	9364·8

IX. *Damp Air.*—The same air as in No. VIII.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9323·4	2	5	9342·7
0	9	9323·9	2	50	9342·9
0	18	9325·9	3	35	9343·9
0	23	9329·9	4	25	9345·9
0	29	9335·9	6	40	9349·9
0	35	9339·9	7	13	9350·9
0	40	9341·9	9	20	9351·9
0	40	Steam issuing freely.	10	40	9351·9
			13	0	9351·9
0	56	9342·7			

X. *Olefiant Gas.*—The absorber was now carefully dried, dry air being drawn through it, while steam was driven through both compartments of the jackets. Then the jacket was filled with water, and the air in the reservoir displaced by dry olefiant gas, made according to the method recommended by Roscoe and Schorlemmer in their *Treatise on Chemistry.* The olefiant gas was driven through drying apparatus into the absorber, the tube C being open to the atmosphere, until the gas issuing from C burned with a white flame.

Time. m.	s.	Pressure.
0	0	9232·3
0	18	9233·3
0	24	9236·3
0	28	9241·3
0	33	9245·3
0	38	9248·3
0	44	9250·3
0	44	Steam issuing freely.
0	50	9251·3
1	0	9252·3
1	10	9253·3
1	18	9254·3
1	30	9255·3
1	45	9256·3
2	4	9257·3
2	22	9258·3
2	50	9259·3
3	50	9261·3
4	45	9264·3
5	45	9266·3
8	0	9271·3
10	0	9274·3
13	7	9277·3
17	0	9277·3

XI. *Dry Air.*—The olefiant gas was next displaced by dry air.

Time. m.	s.	Pressure.
0	0	9087·9
0	10	9088·8
0	15	9093·8
0	20·5	9099·0
0	27	9105·0
0	36	9107·2
0	48·5	9108·3
0	49	Steam issuing freely.
1	0	9110·1
1	11	9110·8
1	25	9112·0
1	57	9114·0
2	40	9117·3
3	38	9120·3
4	56	9124·6
6	45	9130·4
8	23	9139·0
10	0	9143·6
11	54	9150·6
14	41	9158·4
16	34	9165·4
20	10	9174·9
23	0	9181·7
26	15	9190·0
29	53	9197·6
31	58	9202·6
35	40	9209·2

XII. *Dry Air, containing a small quantity of Olefiant Gas.*—A very small quantity of dry olefiant gas was driven into the absorber which contained the dry air already used for Experiment XI.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9256·6	0	53	9274·1
0	8	9257·6	1	5	9274·6
0	15	9258·6	1	51	9275·6
0	20	9259·6	3	44	9276·6
0	24	9261·6	5	45	9278·6
0	29	9266·6	6	32	9279·6
0	34	9268·6	7	54	9281·8
0	40	9272·6	8	51	9282·6
0	41	Steam issuing freely.	10	37	9284·6
			17	46	9286·6
0	44	9273·6	23	18	9288·6

If the above experiments be represented by curves, with intervals of time as abscissæ and increments of pressure as ordinates, it will be seen (1) that the curves have all, except in the case of Experiment XI., the same general form; (2) that the curves for dry air tend, after different intervals of time, to the same value of ordinate, except in the curiously anomalous case of Experiment XI.; (3) that the curves for air containing different quantities of water vapour occupy in all cases a lower position on the diagram than those for dry air; (4) that the curve for olefiant gas is above that for dry air; and (5) that the curve for dry air, containing a small quantity of olefiant gas, is in the same region of the diagram as those for moist air. We thought it worth while, therefore, to try to find how much olefiant gas must be added to dry air to give a curve coinciding with that of air containing a known quantity of vapour.

It seemed advisable, however, to increase the radiating surface relatively to the surface of the absorber. The apparatus which we used for subsequent experiments therefore differed from that already described in two respects. The diameter of the cylindrical absorber was 18 inches, and the plate separating the radiator K from the absorber A was of copper, and $\frac{3}{16}$ in. thick. It was made thick to prevent, as much as possible, its giving way under the pressure to which it was subjected, when the radiator was in com-

munication with the boiler or the water supply. It was made of copper, that its conductivity might be as great as possible.

The curved sides and bottom of the absorber were made as before of the stoutest commercial tinned iron. We thought it unnecessary to have it made more rigid, as the pressure of the water in the jacket was constant during each experiment. The copper plate bent under the pressure of the water and the steam, however, more than we anticipated, and the differences in the amount of the bending caused perceptible changes of form in the sides. The pressures given below are subject therefore to sudden slight variations, which depend upon sudden changes of volume of the absorber, not upon absorption. Hence the numbers given below cannot be taken as exact results. It will be noticed in the experiments made with this apparatus, that after the steam is turned on in the radiator, previously filled with running water, the pressure at first diminishes, and only after a certain time increases. This is not due to absorption, but to the fact that the water pressure in the laboratory was slightly greater than the boiler pressure which we used. When, therefore, the water pressure was taken off the sides of the radiator K, and the steam pressure was put on, the copper plate became less bent, and the reservoir therefore became suddenly larger, the pressure consequently falling. As might be expected, in the case of an apparatus not sufficiently rigid, the first experiments made with it were much more unsatisfactory than the last. The apparatus took gradually the set determined by the pressures employed. If the measurements given in the tables below are plotted, the resulting curves will be found far smoother in the case of the later than in that of the earlier experiments. For more exact experiments a more rigid apparatus should be employed.

For the following experiments a new manometer was used. It was made from a carefully selected tube of practically uniform bore.

The mode of procedure in the experiments with the new reservoir was practically the same as that described above. Tests were applied more frequently to find if the reservoir was air-tight, and to find if the drying tubes were efficient. Their efficiency was tested by weighing at intervals the last of the series.

XIII. *Air saturated with Water Vapour at* 13°·2 *C.*—The absorber being full of air, a small quantity of water was introduced

by the opening D, and poured over the bottom. The absorber was then left standing for an hour. The temperature of the water in the jackets was 13°·2 C.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9023·8	7	24	9054·8
0	27	9019·8	7	42	9056·8
0	45	9018·8	8	30	9059·8
1	13	9018·8	9	5	9062·8
1	20	9019·8	9	40	9064·8
1	36	9020·3	10	35	9067·9
1	45	9020·8	11	5	9074·9
2	4	9021·8	11	40	9076·9
2	26	9022·8	12	23	9080·9
2	46	9023·8	13	2	9089·9
3	0	9024·8	14	20	9094·9
3	15	9025·8	15	20	9099·9
3	35	9027·8	16	0	Steam issuing freely.
3	37	9028·8			
3	51	9029·8	17	20	9109·9
4	7	9031·8	18	18	9111·9
4	25	9033·8	19	10	9112·9
4	36	9034·8	19	30	9113·9
4	55	9036·8	20	36	9114·2
5	5	9038·8	21	6	9124·0
5	15	9039·8	21	38	9125·0
5	53	9044·8	22	30	9125·0
6	40	9049·8	23	50	9125·0
6	55	9051·8	25	25	9126·0

XIV. *Air saturated with Water Vapour at* 13° *C.*—The water and air in the absorber as in Experiment XIII. Temperature of the water jacket was 13° C.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9017·8	1	37	9017·8
0	12	9016·8	2	0	9018·8
0	20	9014·8	2	17	9019·8
1	25	9015·8	2	35	9020·8

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
3	2	9022·8	10	0	9067·8
3	20	9024·8	11	1	9072·8
3	41	9027·8	11	42	9077·8
4	8	9030·8	12	15	9082·8
4	24	9032·8	13	0	9097·8
4	40	9034·8	13	35	9100·8
5	16	9038·8	14	10	9102·8
6	6	9044·8	14	50	Steam issuing freely.
6	27	9047·8	15	20	9107·8
6	50	9050·8	16	10	9109·8
7	5	9052·8	16	55	9112·8
7	28	9055·8	19	40	9122·8
7	55	9057·8	21	16	9123·8
8	50	9062·8	22	50	9124·8
9	15	9064·8			

XV. *Dry Air.*—The absorber was dried by keeping both compartments of the jacket full of steam, and drawing dry air through the absorber until a U-tube of carefully dried calcium chloride placed between C and the suction-pump showed no change of weight in the course of an hour. Both compartments of the jacket were then kept full of running water, of temperature 12°·2 C., until the pressure of the air in the absorber had become constant, when as usual the radiator was put in communication with the boiler.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9088·3	7	0	9117·3
0	19	9087·3	7	50	9122·3
0	28	9086·3	8	7	9127·3
0	45	9085·3	8	50	9133·2
1	10	9086·3	9	15	Steam issuing freely.
1	22	9087·3	9	25	9137·3
1	47	9088·3	10	0	9142·3
2	25	9090·3	11	5	9147·3
2	53	9092·3	16	0	9148·3
3	40	9095·3	18	15	9151·3
4	0	9097·3	23	0	9152·3
5	0	9102·3	24	55	9154·3
5	45	9107·3	28	0	9154·3
6	30	9112·3			
7	0	9115·3			

XVI. *Dry Air.*—The same air as in the last experiment, both compartments of the jacket having been again filled with water until the pressure had become constant.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9085·3	5	30	9107·3
0	14	9084·3	6	20	9113·3
0	20	9083·3	6	47	9117·3
0	26	9082·3	7	25	9122·3
0	36	9081·3	8	0	9127·3
0	53	9080·3	8	0	Steam issuing freely.
1	5	9081·3			
1	14	9082·3	8	31	9132·3
1	40	9084·3	9	16	9137·3
1	55	9085·3	11	10	9140·3
2	9	9087·3	13	2	9141·3
2	50	9092·3	15	50	9142·3
3	37	9097·3	21	35	9142·5
4	35	9102·3	24	0	9142·5

XVII. *Mixture of Air and Olefiant Gas, containing* 1·1 *per cent. by volume of Olefiant Gas.*—The absorber being full of the dry air of last experiment, both compartments of the jacket were filled with running water of temperature 12° C. When the pressure had become constant, and had the value 9154·1, dry olefiant gas was driven into the absorber at B (C being kept closed) until the pressure had risen to 9256·8. Of the gas which the absorber contained, therefore 1·1 per cent. by volume was olefiant gas. The olefiant gas was prepared in the same manner as before, from rectified spirit and pure sulphuric acid.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9173·8	1	25	9174·3
0	11	9173·2	1	38	9176·3
0	24	9172·2	1	47	9178·3
0	30	9171·2	2	4	9181·3
0	45	9170·2	2	21	9184·3
0	55	9171·2	2	30	9186·3
1	7	9172·2	2	38	9189·4

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
2	47	9191·4	6	30	9251·8
3	2	9194·4	6	50	9256·8
3	10	9196·4	7	0	Steam issuing freely.
3	19	9198·4	7	20	9266·9
2	35	9201·4	7	33	9271·9
4	10	9206·4	7	45	9276·9
4	30	9211·5	8	10	9282·0
4	53	9216·5	8	23	9287·0
5	0	9221·6	9	5	9292·0
5	13	9226·6	10	12	9297·1
5	29	9231·6	11	40	9298·1
5	45	9236·6	13	12	9299·1
6	5	9241·7			
6	17	9246·7			

XVIII. *Mixture of Air and Olefiant Gas, containing* 1·1 *per cent. by volume of Olefiant Gas.*—The absorber contained the same gas as before. Both compartments of the jacket had again been kept filled with running water at 12° C. until the pressure had become constant.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9102·8	6	18	9181·3
0	45	9104·8	6	31	9186·3
1	15	9105·8	6	50	9191·4
1	27	9107·8	7	7	9196·4
1	45	9110·8	7	33	9201·4
2	12	9115·9	8	0	Steam issuing freely.
2	35	9120·9	8	12	9211·5
3	0	9125·9	8	24	9216·5
3	18	9131·0	8	51	9221·6
3	40	9136·0	9	25	9226·6
3	57	9141·0	9	50	9231·6
4	17	9146·1	11	35	9233·6
4	40	9151·1	14	10	9235·7
4	55	9156·1	16	20	9236·7
5	15	9161·1	17	17	9239·7
5	32	9166·2	21	5	9240·7
5	48	9171·2	24	0	9241·7
6	4	9176·2			

XIX. *Mixture of Air and Olefiant Gas, containing ·06 per cent. by volume of Olefiant Gas.*—The mixture of dry air and olefiant gas used in Experiment XVIII. was driven out of the absorber by a current of dry air, which was drawn through the absorber for about twenty hours. When both compartments of the jacket had been filled with cold water, and B and C closed, the pressure took the constant value 9289·2. Dry olefiant gas was then driven into the absorber until the pressure took the constant value 9295·4. The gas which filled the absorber contained therefore ·05996 or about ·06 per cent. by volume of olefiant gas. The temperature of the gas at starting was 12°·9 C.

Time. m.	Time. s.	Pressure.	Time. m.	Time. s.	Pressure.
0	0	9299·6	5	40	9349·1
0	22	9298·7	5	55	9354·2
0	48	9298·7	6	5	Steam issuing freely.
1	10	9298·5	6	20	9359·4
1	30	9299·9	6	37	9364·5
1	43	9301·0	7	0	9369·6
2	0	9303·1	7	32	9371·6
2	16	9306·1	7	47	9375·8
2	28	9308·2	8	27	9377·1
2	55	9313·3	10	35	9378·3
3	20	9318·4	12	32	9379·8
3	45	9323·5	14	10	9381·2
4	13	9328·7	18	10	9383·0
4	35	9333·8	20	54	9383·4
4	57	9338·8			
5	15	9344·0			

XX. *Mixture of Air and Olefiant Gas, containing ·06 per cent. by volume of Olefiant Gas.*—The absorber contained the gas used in Experiment XIX. Both compartments of the jacket having been filled with water at 12°·8 C., and the pressure having taken a constant value, the steam was turned on in the radiator.

Time. m.	Time. s.	Pressure.	Time. m.	Time. s.	Pressure.
0	0	9296·1	0	24	9294·3
0	16	9295·3	0	30	9293·3

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	54	9292·3	5	15	9341·6
1	15	9293·3	5	35	9346·6
1	30	9295·3	5	55	9351·7
1	40	9296·3	6	15	9356·7
2	14	9301·4	6	35	9361·7
2	37	9306·4	6	50	Steam issuing freely.
3	8	9311·4			
3	32	9316·4	7	4	9367·8
4	0	9321·4	7	23	9371·8
4	15	9326·5	7	48	9376·8
4	36	9331·5	8	27	9381·9
4	55	9336·6	9	13	9383·9

The bursting of the steam tube brought this experiment to an end.

XXI. *Mixture of Air and Olefiant Gas, containing* ·06 *per cent. by volume of Olefiant Gas.*—The same gas as that used in Experiment XIX. and XX. The absorber had again been completely surrounded by water at 12°·85 C., and the pressure had become constant.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9303·9	5	52	9353·2
0	5	9302·9	6	13	9358·3
0	23	9301·9	6	33	9363·3
0	30	9299·9	6	55	9368·3
0	47	9298·9	7	0	Steam issuing freely.
1	7	9299·9			
1	30	9302·9	7	15	9373·4
2	10	9308·0	7	35	9378·4
2	42	9313·0	8	0	9383·4
3	12	9318·0	8	30	9388·5
3	45	9323·0	9	50	9391·5
4	7	9328·1	11	3	9392·5
4	30	9333·1	12	32	9393·5
4	55	9338·1	15	33	9394·5
5	13	9343·2	19	30	9395·5
5	32	9348·2	22	25	9396·0

XXII. *Mixture of Air and Olefiant Gas, containing* 0·2 *per cent. by volume of Olefiant Gas.*—The absorber, containing the same gas as in the Experiments XIX., XX., and XXI., was surrounded by water at 12°·8 C., and the pressure when constant was found to be 9305·6. Dry olefiant gas was then driven in until the pressure had taken the constant value 9318·3. The mixture therefore contained ·19969 or about ·2 per cent by volume of olefiant gas.

Time. m.	Time. s.	Pressure.	Time. m.	Time. s.	Pressure.
0	0	9318·3	6	12	9375·1
0	19	9317·7	6	30	9380·2
0	29	9315·7	6	52	9385·2
0	41	9314·7	7	10	9390·2
0	57	9315·7	7	30	9395·3
1	7	9316·7	7	50	9400·3
1	31	9319·8	8	0	Steam issuing freely.
2	14	9324·8	8	16	9405·3
2	45	9329·8	8	45	9410·4
3	12	9334·9	9	15	9412·4
3	36	9339·9	10	2	9415·4
4	1	9344·9	10	45	9416·4
4	28	9350·0	14	51	9418·4
4	50	9355·0	17	0	9419·4
5	12	9360·0	21	15	9419·4
5	34	9365·1			
5	55	9370·1			

XXIII. *Mixture of Air and Olefiant Gas, containing* 0·2 *per cent. by volume of Olefiant Gas.*—The absorber, containing the same mixture as in Experiment XXII., was surrounded by water at 12°·8 C., till the pressure had assumed a constant value. Then as usual the water was turned off from K, and the steam turned on.

Time. m.	Time. s.	Pressure.	Time. m.	Time. s.	Pressure.
0	0	9323·1	0	58	9320·1
0	13	9322·1	1	5	9321·2
0	27	9321·1	1	23	9323·2
0	33	9320·0	1	44	9326·2
0	46	9319·0	2	15	9331·3

Time.		Pressure.	Time.		Pressure.
m.	s.		m.	s.	
2	41	9336·3	6	47	9397·0
3	10	9341·4	7	8	9402·1
3	35	9346·4	7	15	{ Steam issuing freely.
3	55	9351·5	7	25	9407·1
4	16	9356·5	7	48	9412·2
4	37	9361·6	8	33	9417·3
4	57	9366·7	10	20	9419·4
5	16	9371·8	12	45	9420·6
5	45	9376·8	18	0	9421·6
6	0	9381·9	20	0	9421·8
6	13	9386·9			
6	30	9391·9			

XXIV. *Dry Air.*—The mixture of air and olefiant gas contained in the absorber in Experiment XXIII. was displaced by a current of dry air of about 47 c.c. per second (as determined by experiment), which was drawn through the apparatus for seven hours. At the end of that time (as determined by calculation) only about ·2 × ·0005 or ·0001 per cent. of the gas contained in the absorber would be olefiant gas.[1] A set of observations was made with this practically pure air, the temperature of the water jacket being 12°·9 C.

Time.		Pressure.	Time.		Pressure.
m.	s.		m.	s.	
0	0	9375·2	5	45	9417·5
0	51	9374·2	6	20	9422·6
1	18	9377·3	7	0	{ Steam issuing freely.
1	46	9380·3	7	3	9427·6
2	0	9382·3	7	47	9432·6
2	30	9387·3	9	15	9435·6
3	13	9392·4	10	15	9436·6
3	43	9397·4	14	0	9437·7
4	13	9402·4	22	0	9438·2
4	40	9407·5			
5	15	9312·5			

[1] If v is the volume of air entering in unit time, w the percentage of olefiant gas present after t units of time, w_0 the percentage present at beginning, and V the volume of the reservoir,

$$w = w_0 e^{-\frac{v}{V}t}.$$

XXV. *Mixture of Air and Olefiant Gas, containing* ·032 *per cent. by volume of Olefiant Gas.*—The absorber, filled with the dry air of Experiment XXIV., was surrounded by water at 12°·6 C. When a constant pressure of 9338·5 had been attained, dry olefiant gas was driven into the vessel, raising the pressure to 9341·5. Hence the mixture contained ·032 per cent. by volume of olefiant gas.

Time. m.	Time. s.	Pressure.	Time. m.	Time. s.	Pressure.
0	0	9340·9	5	30	9374·0
0	17	9339·9	6	13	9379·1
0	26	9338·9	6	52	9384·1
0	54	9336·9	7	15	Steam issuing freely.
1	14	9338·9			
2	0	9343·9	7	50	9394·1
2	38	9349·0	8	24	9399·1
3	10	9354·0	10	15	9404·1
3	41	9359·0	12	20	9405·0
4	13	9364·0	13	50	9406·0
4	53	9369·0	19	10	9406·4

XXVI.—*Damp Air, containing* 1·3 *per cent. by volume of Water Vapour.*—A current of the damp air of the laboratory was drawn through the absorber, which contained initially the gas in Experiment XXV., until, as determined by calculation, it contained a quantity of olefiant gas so small as to be negligible. The quantity of water vapour present in the damp air, with which the reservoir was then filled, was found by determining the dew-point. The room in which the experiments were carried out was large, and there was a slow passage of air through it. The dew-point was determined by observation of wet and dry bulb thermometers. The temperatures they indicated were respectively 15° and 12°·8 C. The barometric pressure (reduced to 0° C.) was 759·83 mm. The pressure of the water vapour was therefore 9·71 mm., and the damp air contained consequently 1·278 (or about 1·3) per cent. by volume of water vapour.

Time. m.	Time. s.	Pressure.	Time. m.	Time. s.	Pressure.
0	0	9331·6	0	55	9329·1
0	25	9330·1	1	17	9330·0

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
1	35	9333·0	7	0	Steam issuing freely.
2	8	9338·0	7	9	9400·1
2	35	9343·0	7	24	9405·1
3	0	9348·0	7	42	9408·1
3	27	9354·1	8	8	9413·1
3	48	9358·1	8	30	9418·2
4	8	9363·0	9	42	9423·1
4	25	9368·0	11	42	9425·0
4	47	9373·1	13	45	9425·9
5	30	9378·1	14	35	9426·8
5	58	9383·1	21	0	9427·1
6	25	9390·1			
6	42	9392·1			

XXVII. *Air saturated with Water Vapour at* 12°·4 *C.*—Water had been put inside the absorber twelve hours before the experiment, and some of it was still lying unevaporated in the vessel. The air therefore was saturated. The temperature of the water jacket when the reservoir was completely surrounded by water, and the pressure was constant, was 12°·4 C. Hence the pressure of water vapour was about 10·68 mm. The barometric pressure (reduced to 0° C.) was 757·65 mm.

Time. m.	s.	Pressure.	Time. m.	s.	Pressure.
0	0	9306·4	6	14	9353·0
0	33	9304·4	6	56	9358·1
1	8	9304·4	7	27	9363·2
1	30	9307·4	8	2	9368·3
2	8	9312·5	8	25	9373·3
2	43	9317·5	8	30	Steam issuing freely.
3	14	9322·6	8	51	9378·4
3	42	9327·6	10	0	9383·5
4	10	9332·8	12	45	9387·6
4	35	9337·8	16	30	9388·9
4	59	9342·9	19	30	9390·1
5	20	9348·0			

If these experiments be represented by curves after the same

manner as the former ones, the following results become apparent: —(1) The manometric effect is very much greater with the new than with the old apparatus. (2) The curves for any one gas, or mixture of gases, do not coincide with one another. Thus corresponding ordinates of the two curves for air containing 1·1 per cent. of olefiant gas differ by about 4 or 5 per cent., or, as it may be put, one curve is 4 or 5 per cent. lower than the other. Of the two curves for air with 0·2 per cent. of olefiant gas, one is 2 to 4 per cent. lower than the other. Of the two for air with 0·06 per cent. of the same gas, one is from 6 to 10 per cent. lower than the other. Hence the apparatus used was incapable of giving perfectly accurate results. As we have pointed out above, the reservoir was not sufficiently rigid. With a rigid reservoir the curves for any one gas, or gaseous mixture, would coincide at any rate in those portions corresponding to considerable intervals of time; but the inevitable difference in the initial conditions of the experiments must in general prevent entire coincidence in portions corresponding to short intervals of time. (3) The dry air curves are with this apparatus the lowest on the diagram. To us this result was unexpected; but Professor Tait had foreseen it as a consequence of the change of dimensions of the apparatus. (4) As in the preliminary experiments, the curves for air containing olefiant gas and for air containing water vapour occupy the same region of the diagram. The relative positions of the curves may be used to determine the relative absorptive powers of the gaseous mixtures. (5) The curves for air containing different quantities of olefiant gas occupy positions extending over a considerable area of the diagram, and they are higher the greater the percentage of olefiant gas (from ·032 up to 1·1). By determining a sufficient number of such curves a scale of absorptive power may be formed, to which the absorption of air containing known quantities of vapour may be referred. With our apparatus it was impossible to form such a scale accurately for the reasons given above. But an approximate result is given by our experiments. The curve for air with 1·3 per cent. of water vapour (not saturated) has above it the two curves for air with 0·2 per cent. of olefiant gas, and below it the two curves for air with 0·06 per cent. of olefiant gas. Hence we may conclude that the absorption of air containing 1·3 per cent. of water vapour is between that of air con-

taining 0·06 per cent. and that of air containing 0·2 per cent. of olefiant gas. With a rigid reservoir it would be possible to determine exactly the constitution of mixtures of air and olefiant gas, and of air and water vapour having equal absorptive powers.

The above experiments were made in Professor Tait's laboratory during the summer vacation of 1882. By the time they had advanced thus far my vacation was at an end, and I could not wait to get a new reservoir constructed and to complete them. I hope Professor Tait may be able to complete them at an early date.

I must mention with gratitude the enthusiastic assistance rendered me by Mr Lindsay. His cheerful contempt of failure and his ready resource in difficulty contributed largely to whatever of success we attained. We are deeply indebted to Professor Crum Brown for the use of apparatus necessary for the making of olefiant gas. Of course Professor Tait took a most lively interest in our results, and we had at all times the benefit of his advice.

4. Note on the Compressibility of Water. By Professor Tait

To test by an independent process the accuracy of the unit of my pressure gauge, on which the estimated corrections for the "Challenger" deep-sea thermometers depend, it was arranged that H.M.S. "Triton" should visit during the autumn a region in which soundings of at least a mile and a half could be had. A set of manometers, filled with pure water, and recording by the washing away of part of a very thin film of silver, were employed. They were all previously tested, up to about $2\frac{1}{2}$ tons weight per square inch, in my large apparatus. As I was otherwise engaged, Professor Chrystal and Mr Murray kindly undertook the deep-sea observations; and I have recently begun the work of reducing them.

The first rough reductions seemed to show that my pressure unit must be somewhere about 20 per cent. too small. As this was the all but unanimous verdict of fifteen separate instruments, the survivors of two dozen sent out, I immediately repeated the test of my unit by means of Amagat's observed values of the volume of air at very high pressures. The result was to confirm, within 1 per cent., the accuracy of the former estimate of the unit of my gauge. I then had the manometers resilvered, and again tested in the compression

apparatus. The results were now only about 5 per cent. different from those obtained in the "Triton." There could be no essential difference between the two sets of home experiments, except that the first set was made in July, the second in November,—while the temperatures at which the greatest compressions were reached in the "Triton" were at least 3° C. lower than those in the latter set. Hence it seems absolutely certain that water becomes considerably more compressible as its temperature is lowered, at least as far as 3° C. (the "Triton" temperature). This seems to be connected with the lowering by pressure of the maximum density point of water, and I intend to work it out. It is clear that in future trials of such manometers some liquid less anomalous than water must be employed.

Another preliminary result, by no means so marked as the above, and possibly to be explained away, is that by doubling (at any one temperature) a high pressure we obtain somewhat less than double the compression. This, however, may be due to the special construction of the manometer, which renders the exact determination of the fiducial point almost impossible.

5. Note on an Application of Mendeleieff's Law to the Heats of Combination of the Elements with the Halogens. By Mr A. P. Laurie. Communicated by Professor Crum Brown.

Monday, 15th January 1883.

Professor MACLAGAN, Vice-President, in the Chair.

The Chairman, in accordance with the Laws, announced to the meeting the names of proposed new Foreign and British Honorary Fellows, to be submitted for Ballot at the Second Meeting in February, viz.—*As British Honorary Fellows*:—Sir Joseph Dalton Hooker, Dr William Spottiswoode, Professor Alexander William Williamson, Colonel H. Yule. *As Foreign Honorary Fellows*:—Professor Luigi Cremona, Dr Julius Hann, Professor Charles Adolphe Wurtz.

The following Communications were read :—

1. The Diurnal Variation of the Force of the Wind on the Open Sea and near Land. By Alexander Buchan, M.A.

2. On the Semitic and Greek Article. By the Rev. Dr Teape.

3. On the Nature of Solution. By W. W. Nicol, M.A., B.Sc.

4. On the Relative Electro-Chemical Positions of Wrought Iron, Steels, Cast Metal, &c., in Sea Water and other Solutions. By Thomas Andrews, Assoc. M. Inst. C.E., F.C.S. Communicated by Professor Crum Brown.

BUSINESS.

The following candidate was balloted for, and declared duly elected a Fellow of the Society :—Dr R. Peel Ritchie.

Monday, 29th January 1883.

THOMAS STEVENSON, Esq., M. Inst. C.E., Vice-President, in the Chair.

1. Observations of the Rainband from June 1882 to January 1883. By Hugh Robert Mill, B.Sc., F.C.S. Communicated by Professor Tait. (Plate I.).

The series of observations to be described was undertaken in order to ascertain how far a small pocket spectroscope could be relied upon for the prediction of rain, with a view to its popular use for that purpose.

The instrument employed was Hilger's smallest sized direct-vision spectroscope, its length being one inch and a half, and its diameter half an inch. It was furnished with the ordinary adjustable slit, and had no special provision for the exclusion of dust. It is desirable, however, to use an instrument which has the eyehole protected by a plate of thin glass, and the slit covered with a thicker plate. In this case care must be taken to keep the glass free from scratches, which greatly obscure the spectrum.

When the spectroscope is to be used the slit is made as narrow as

possible, and the focus adjusted until the spectrum appears bright and clear, with the black solar absorption lines crossing it vertically. If there is dust on the slit each grain appears drawn out into a thick black line running through the spectrum horizontally. When these horizontal lines are seen the slit should be cleaned by gentle brushing with a camel-hair pencil.

The spectrum of clear sky or a bright cloud, in the instrument used, is a coloured strip apparently about an inch long and half an inch wide. On one side a band of red, apparently $\frac{3}{16}$ths of an inch wide, emerges from blackness and shades into a $\frac{1}{16}$th inch strip of yellow, which merges into a quarter inch space of green, passing into an equal area of blue which dies away in hardly visible violet. Two or, in favourable circumstances, three black lines (*a*, B, C) are seen in the red, one (D) appears to separate the red from the yellow, a wide nebulous line divides the yellow from the green, several very thin lines appear in the green together with two thicker ones (E and *b*), and in the beginning of the blue there is a still darker line (F); besides which a glimpse may sometimes be had of other lines in the darker part of the spectrum beyond F. On looking directly at the sun many of the lines are split up into a number of very fine components, and the whole spectrum seems ruled with lines intensely black and geometrically narrow, most of which are invisible in diffused light. The nebulous line between the yellow and green is usually mistaken for the rainband at first, for it varies in intensity from time to time. A more particular observation shows that its intensity at any time is proportional to the sun's nearness to the horizon, but it appears to be sometimes affected by other causes. Professor Piazzi Smyth has shown that this is a dry air absorption band, and he defines it as "a function of dry air and low sun." The real rainband cannot be seen by itself in the little spectroscope, but an acquaintance with the spectrum soon shows that the width of the D-line is not constant, and that when widest it seems to shade off gradually towards the red, resembling a line ruled by a fine pen with a very small hair in its point. It can easily be shown that this widening is not due to a widening of the solar sodium absorption line, by looking at the sky spectrum through the flame of a Bunsen lamp faintly tinged yellow with a sodium salt. The D-line proper is thus replaced by a brilliant yellow streak, and the rainband is seen

as a black line clinging to its red side. This narrow blurred line represents the hundreds of thin lines produced by the absorptive power of the water-vapour in the atmosphere, which can be seen by using an instrument of sufficient power; and although it is never seen alone or measured by itself, it can be employed as a valuable weather indicator.

The rainband was always observed by looking as near the horizon as possible, so as to take advantage of the greater depth of air seen through; the focus was carefully adjusted to give the sharpest possible definition of the solar lines, and then the intensity of the band together with the D-line was noted. The rainband has been represented by the letter π, and the compound line, which was always measured, may be written shortly as $D + \pi$.

The great difficulty in recording observations is to obtain a constant scale of intensities. It has usually been the practice to judge of the intensity of the band by the eye, and to record it on a scale of 1 to 5 or 1 to 10, or else to measure it in terms of the low-sunband. The former plan possesses the disadvantage common to all purely mental scales, that there is no guarantee of the intensity which is represented by a certain figure one day being recognised as corresponding to that figure on another occasion. Changes in the illumination of the spectrum or in the condition of the observer can hardly fail to make some difference. The second plan is free from this defect to a great extent, but it is inconvenient, for beginners at least, because of the diurnal variations of the low-sunband. Various mechanical arrangements were tried in order to furnish a scale which would remain constant and could be readily reproduced, but the results of the experiments were not very satisfactory, and it therefore seemed advisable to employ a relative scale supplied by the spectroscope itself. The spectrum observed was so small that the principal Fraunhofer lines were brought near enough to be used as standards of comparison, and as the moisture in the air does not affect their relative intensities, the three most prominent (E, *b*, and F) were fixed upon as the units of the scale. The three increase in darkness in the order E, *b*, F, and they are, roughly speaking, darker in proportion to their distance from D. The method of measuring by this scale does not altogether get over the objection attached to the use of a mental scale, although that

objection is reduced to a minimum; and the method at best is only applicable to small instruments. A spectroscope of sufficient dispersion to split D, or even *b*, in diffused light would entirely alter the appearance of the lines, and the rainband would appear as a *band* incapable of comparison with them. With the small spectroscope used on a clear sky the D-line appears about equal to E in intensity when the rainband is at a minimum. As the band increases the D-line appears wider, becoming in turn equal to *b*, equal to F, and greater than F. In this way six shades of intensity may be easily distinguished, and these may be represented shortly as—

$$\begin{array}{ll} D + \pi = E. & \\ \;\;\;\;,, & > E < b. \\ \;\;\;\;,, & = b. \\ \;\;\;\;,, & > b < F. \\ \;\;\;\;,, & = F. \\ \;\;\;\;,, & > F. \end{array}$$

The words *wide*, *dark*, *black*, and *intense*, when applied to the rainband and the larger spectral lines, mean the same thing, for it is difficult to say whether a large rainband makes the D-line apparently blacker, or wider, or both, when viewed by the small spectroscope.

Another point of some importance in the prediction of rain is, as has been pointed out by Mr Rand Capron, the visibility of the thin lines in the green. These vary greatly in distinctness, being sometimes invisible and at other times very apparent, but it is difficult to avoid changing the value of the words used to express the different degrees of visibility. A long and intimate acquaintance with the spectrum in its different appearances is necessary in order to overcome this difficulty.

A regular record of the intensity of the rainband has been kept since June 1882, and the weather which followed within twelve hours of each daily observation at 9 A.M. has also been noted. Other meteorological observations were subsequently introduced to supplement those of the rainband, but during the first seven months the latter alone were considered, and a prediction founded thereon was written down each morning. The degree of intensity warranting a prediction of rain was, of course, entirely a matter of experience, each success or failure modifying to a certain extent the

basis of the next prediction. At first it was only necessary to use the lines b and F for comparison, since $D + \pi$ was very rarely $< b$ during the months of June, July, August, and September. It was soon observed that rain seldom fell within twelve hours when the D-line at 9 A.M. appeared less than or equal to b, and that rain almost always followed when it appeared equal to or greater than F. Intermediate intensities were much more common, and in order to make predictions in these cases the degree of visibility of the thin lines in the green was taken into account. From the daily observations in the month of June the following table for predicting was drawn up:—

$D + \pi$

$=$ or $< b$	$> b < F$	$=$ or $> F$
No rain	Thin lines	Rain

Thin lines: Distinct	Thin lines: Indistinct
Probably No rain	Probably Rain

This table held closely during July. In that month the intensity was $=$ or $>$ F on fourteen occasions, and rain followed on thirteen of these. The intensity was $> b < F$ with thin lines indistinct seven times, and rain followed six times; on six days the intensity was the same, but the thin lines were distinct, and rain (in each case only a slight shower) followed on three. Once the intensity was $= b$, and it was followed by a slight shower. The table was also applicable, though less accurately, to August, September, and October, but in November its predictive power completely broke down. The intensity was $=$ or $< b$ twenty-four times in that month, and rain followed on fourteen of these days. The probable reason of this is the low temperature which prevailed, in consequence of which a small quantity of water-vapour produced saturation, which was thus indicated by a fainter rainband than in previous months. A new table of predictions required to be framed for the winter months, in which the intensities $D + \pi > E < b$, and $= E$ were considered.

The following table (Table I) shows the number of times which

the rainband attained each intensity in each of the seven months, and how often it was followed (within twelve hours) by rain in each case :—

TABLE I.

1882. Month.	$D+\pi>F$.	Rain followed.	$D+\pi=F$.	Rain followed.	$D+\pi>b<F$. Thin Lines. Indistinct.	Rain followed.	Distinct.	Rain followed.	$D+\pi=$or $<b$.	Rain followed.
June,	8 times	6 tms.	4 times	4 tms.	3 tms.	2 tms.	6 tms.	4 tms.	9 times	5 tms.
July,	11 „	11 „	3 „	2 „	8 „	7 „	6 „	3* „	1 „	1* „
August,†	4 „	4 „	10 „	5 „	6 „	3 „	10 „	1 „	0 „	0 „
September,	3 „	3 „	9 „	6 „	9 „	3 „	5 „	1 „	4 „	0 „
October,	7 „	6 „	4 „	4 „	9 „	6 „	2 „	0 „	8 „	3 „
November,	0 „	0 „	3 „	3 „	1 „	1 „	2 „	2 „	24 „	14 „
December,	4 „	4 „	2 „	2 „	7 „	5 „	1 „	1 „	12 „	5‡ „
Total,	37 „	34 „	35 „	26 „	43 „	27 „	32 „	12 „	58 „	28 „

*Very slight showers. † Observations this month were made at Callander.
‡Rain or much snow.

The following summary (Table II) shows that the probability of rain falling increases with the increase of intensity of the rainband in a very regular manner. When $D+\pi$ was $=$ or $<b$ rain followed more frequently than might be expected, but fourteen of these occasions were in the cold month of November and five in December, and on many occasions there were only slight showers.

TABLE II.

$D+\pi$	Number of times.	Rain followed. No. of times.	Rain followed. or per cent.
$=$ or $<b$	58	28	48
$>b<F$ Thin lines distinct	32	12	37 } 50
$>b<F$ Thin lines indistinct	43	27	63 } 50
$=F$	35	26	74
$>F$	37	34	92

The dependence of the rainband on the probability of rain is

perhaps more clearly seen when one or two very slight showers on an otherwise fine day are classed as "no rain," and this is evidently a fairer way of estimating the predictive power than by considering a day on which "no rain" was predicted and a trifling shower occurred as a failure. A better plan would be to omit all days on which there were only slight showers, and simply take account of those on which there was no rain at all or else heavy rain, sufficiently heavy, for example, to interfere with outdoor work. In Table III. it is seen that the increase in intensity of the rainband is not followed by a perfectly regular increase in the percentage of rainy days, which is probably due to the scale not being perfectly uniform, and that a dark rainband is a much surer prognostic of a wet day than a faint one is of dry weather.

TABLE III.

Intensity $D+\pi$	Percentage of rain following.	Percentage of "no rain" following.
$=$ or $<b$	27	73
$>b<F$	38	62
$=F$	74	26
$>F$	92	8

This table represents the results for seven months, classing one, or at most two, slight showers as "no rain." Since the extreme values of the intensity of the rainband illustrate its predictive power most strikingly, it may help to show the importance of such observations, if a short account is given of the various cases in which $D+\pi$ was registered as $>F$ and as $<b$ during the seven months under consideration. During these months there were thirty-seven cases of $D+\pi>F$, and on three of these no rain followed within twelve hours. Two of these mornings of failure were very misty, but the third was bright and clear. On ten occasions heavy showers came on in the *afternoon*. On one of these occasions (July 1st) there was a thunderstorm, on another (September 1st) the rainband, according to Professor Piazzi Smyth, was the darkest for the whole year. There were heavy showers in the *forenoon* on three days and showers at irregular intervals on ten, two of which (July 6th

and August 13th) were accompanied by thunderstorms. On nine days rain fell continuously, and on two there was continual snow. There were thus 8 per cent. of unsuccessful, and 92 per cent. of successful, predictions when the rainband was at its maximum. It was found that on twenty-eight occasions $D+\pi$ was $<b$. On eighteen of these no rain whatever followed for twelve hours, on four one, or at most two, slight showers followed. On four considerable rain, and on two a considerable amount of snow fell. There were thus 21 per cent. of erroneous, and 79 per cent. of successful, predictions when the rainband was its minimum of intensity.

Table IV. gives a summary of all the predictions made from June to December 1882, with the fulfilments. These predictions were

TABLE IV.

	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Rain predicted,	17	22	20	21	20	12	13	125
,, followed,	15	20	12	12	16	11	11	97
Per cent. fulfilled pred.,	88	91	60	57	80	92	85	78
"No rain" pred.,	13	7	10	9	10	18	13	80
,, followed,	7	3	9	8	7	9	8	51
Per cent. fulfilled,	54	43	90	89	70	50	62	64
Total predictions,	30	29	30	30	30	30	26	205
,, fulfilments,	22	23	21	20	23	20	19	148
,, percentage,	74	79	70	67	77	67	73	72

made from spectroscopic evidence alone, the barometer and thermometer were not consulted. In the table "no rain" means that no rain whatever fell during the twelve hours following the prediction. This, as explained when describing Table II., accounts for the apparently greater accuracy of "rain" than "no rain" predictions.

The success of a prediction has been judged of uniformly from the frequency, duration, and intensity of the showers which followed, and not by the rainfall in inches. This was done because the situation of the observing station (in the south side of Edinburgh) was unfavourable for the use of a rain-gauge; and as each prediction was made for a period of twelve hours, the published rainfall for the

vicinity for periods of twenty-four hours did not form a trustworthy index of the success of a prediction. If observations could be made twice or three times a day, so that each prediction would cover a shorter time, and if the intensities of the rainband in different directions were compared each time, much more decided proofs of the utility of the spectroscope as a short-period predictor might reasonably be expected. Situation and circumstances rendered it possible only to make an observation on the north-west sky each morning at 9 A.M., hence all the results described in this paper are deduced from observations in that direction at that hour. If possible the observation should be made on a piece of clear sky, but the spectrum of the light from clouds is not necessarily untrustworthy. Out of 120 consecutive predictions 75 per cent. of those made on a clear, and 73 per cent. of those on a cloudy, sky were verified. The spectroscope cannot be used in a thick mist or a snow-storm, and its indications in frosty weather are usually too faint to be of much value, although it may almost always be relied upon to predict a thaw at least one day beforehand.

Remarks on the Chart for January 1883.

During the month of January 1883 the barometer and thermometer were observed as well as the spectroscope, and the accompanying chart embodies the results obtained.

The shading in the upper half of the column allotted to each day represents the prediction, that in the lower half shows the degree of fulfilment. When the upper half is blank (*e.g.*, the 2nd) "no rain" was predicted, and a blank lower half (*e.g.*, the 4th) shows that no rain fell. A very light shading in the upper half (*e.g.*, the 3rd) denotes a prediction of "probably a little rain," slightly darker (*e.g.*, the 5th) means "some rain," while the very dark (as on the 1st) stands for "rain." The lower half shows the rain which followed up to 9 P.M., the length, position, and darkness of the parts shaded representing approximately the duration, time, and heaviness of the showers. Snow is shown by peculiar shading, as on the 27th. The first and second curves join the points at which the barometer and thermometer stood each morning at 9 o'clock, and the third exhibits the intensity of the rainband in a similar manner. A rise in this curve corresponds to an increase in the

intensity of the band. The fourth line, which could scarcely be represented by an ordinary curve, illustrates the visibility of the thin lines in the green on the scale—

Invisible, Indistinct, Pretty distinct, Distinct,

but for reasons already stated this curve is less reliable than the others.

Summing up the results, it is seen that on sixteen days the prediction was that more or less rain would fall, and that this was verified on fourteen, or 87 per. cent. "No rain" was anticipated on the remaining fifteen days, and on twelve of them, or 80 per cent., there was no rain. The mean percentage of successful forecasts (83·5) is not altered by omitting those days on which only slight showers occurred. The 11th and 19th are the most marked instances of erroneous prediction shown on the chart. It is interesting to notice the general closeness with which the rainband curve follows that of temperature. This is strikingly shown for maxima on the 1st, 17th, and 24th, and for minima on the 4th, 8th, 26th, and 31st. When the divergence of the curves is considerable the nature of the weather to follow is always decided. Thus, when the thermometer is low and the rainband strong, rain is certain to follow, as it did on the 3rd and 21st for example, and when there is a high thermometer and a faint band there will be no rain, for instance, the 7th, 15th, and 20th.

One great secret of successful rainband predicting seems to lie in making proper allowance for the temperature, and the direction and force of the wind have also a share in modifying the data.

2. The Theory of Monopressures applied to Rhythm, Accent, and Quantity. By the Rev. J. L. Blake. Communicated by Professor Crum Brown.

3. On the Effect of Oil on a Stormy Sea. By Mr John Aitken.

The calming effect of oil on troubled waters is so well known and so often referred to, that we might have expected there would, by this time, have been a considerable amount of written information on the subject. This calming effect of oil is not only well

known, but it has also become so stereotyped by constant repetition, that it seems to have acquired the stamp of classical antiquity upon it, yet one is surprised to find that reference to it in early writers is strangely conspicuous by its absence. Our knowledge of the subject seems to have lived almost entirely in tradition.

It is only within the last year that anything like definite attempts have been made to test practically and on a large scale the effect of oil on the waves of the sea. The first of these experiments were made in March last at Peterhead by Mr Shields of Perth, who has taken great interest in the matter. Later on in December last he made other experiments at the entrance to the Aberdeen harbour. The place selected by Mr Shields for the latter experiments was within the entrance channel, at a point about 270 yards inside the furthest point of the north pier, and at rather more than 700 yards outside the entrance to the tidal harbour. The channel is at this point somewhat contracted, and has a breadth of about 240 yards. To distribute the oil over the water, Mr Shields erected a hand pump on the north pier, and connected it with a pipe 1 inch in diameter, which was laid on the bottom of the channel and carried out more than half way across it. The oil was pumped through this pipe, and escaped near the middle of the channel by three valves and roses placed across it 50 feet apart, so as to distribute the oil over some breadth. The oil pumped through the pipe rose to the surface in small globules and spread itself over the water. The effect was very marked and decided. The oil smoothed over the waves and prevented the formation of dangerous crests; the entrance to the harbour was thus made much safer for vessels. Mr Shields deserves great credit for these experiments made on so large a scale, and it is much to be regretted that this method of calming the waves is not less expensive. Each of the experiments at Aberdeen lasted for one hour; the value of the oil used in each was about £20, and though the effect remained for an hour after the pump was stopped, yet the expense does seem great. I am not aware if any experiments were tried to use less oil, but it is evident that it is possible to use too much. There is just one quantity which will give the maximum effect; more or less will not do so well.

Since the experiments at Peterhead and Aberdeen called attention anew to the subject, a number of explanations of this peculiar action

of oil have been given; none of these, however, appear to me to account for the facts. I have therefore ventured to place the following experiments and a theory built upon them before this Society; and though this theory may not appear to some to explain all the phenomena, yet, as it calls attention to certain effects of an oily film, the importance of which has not previously been taken notice of, I trust the subject may not be uninteresting, and may at least be of some little aid in helping forward a proper understanding of this most interesting and difficult subject.

The wonderful effect of oil on water has suggested to many observers the idea that the effect was due to the oily film offering less resistance to the wind than the clean water surface; that the oil so to speak greased the wind. The first thing therefore which seemed necessary to be done was to test whether there was any truth in this supposition; to arrange some experiment to ascertain whether there was less friction between air and an oily film than between air and a clean film. The method adopted was to place some water in a circular vessel, and arrange a jet of air so that it should blow over the surface of the water, and cause it to take up a motion of rotation. Under these conditions the rate of rotation of the water would—if the pressure of the air jet was kept constant—depend on the amount of friction between the air and the water surface. If the oil decreased the friction the water would be driven less quickly under an oily than under a clean film.

In order to measure the amount of motion communicated by the air to the water, a horizontal paddle, completely submerged, was hung in the middle of the vessel by means of a fine platinum wire, the upper end of the wire being attached to a torsion-head. A needle, rigidly attached to the paddle, indicated on a circular scale the amount of torsion produced by the moving water, that is, showed the amount of energy communicated by the air jet to the water. The air jet was supplied from a gasometer, which could be loaded to different pressures.

The following is the method adopted in working this instrument. The circular glass vessel was carefully washed, and filled with water up to a certain height, which was accurately adjusted for each experiment, so that the water was always exactly the same distance below the jet. Air at a low pressure was then blown over the water,

and the angle of torsion noted. The pressure in the gasometer was then raised, a stronger current was blown over the water, and the reading again taken. In this way a number of readings were taken at different pressures, the angle of course increasing with the pressure. After taking two or three series of such readings to get an average for the clean water surface, a little oil was put on the water, and another series of readings taken. The result of these experiments was that there was no decrease in the amount of deflection after the oil was added to the water; which shows that as the air communicated the same amount of motion to the oily surfaced water as it did to the clean surface, therefore oil does not reduce the bite, grip, or friction of the air on the water.

In working with this apparatus it was found very difficult to get constant readings. On making a new experiment, after washing the glass vessel, some change seemed to take place, and the readings for the corresponding pressures were not always the same as the previous ones. The general result, however, was that the oil in a few cases slightly decreased the readings, but in most cases it increased them a little. The difference in the readings in the experiments with clean water, seems in some way to be connected with the resistance offered by the film where it is attached to the sides of the vessel, and the slight increase given in most cases by the oily film may possibly be due to the weakening of this film by the oil.

In the experiments described, the surface film simply circulated in the vessel and but little free surface was developed; if, however, a division plate was put across the vessel just deep enough to stop the easy circulation of the film, an interesting and curious result was obtained. When the pressure of the air jet was low, so that it did not greatly agitate the surface, and the surface film could circulate quickly enough, there was then scarcely any difference between the readings given by the clean and by the oily surface. But when the pressure rose and the agitation of the water became great, a sudden increase in the amount of deflection took place; but this increase always occurred at a lower pressure with the oily than with the clean film, the explanation of which would seem to be, that when greatly agitated by the air new surface film requires to be rapidly developed, and, as it gets no aid from the contracting film

in front, this new surface film can be developed by a lower air pressure in the weak oily film than it can in the stronger clean film. This extreme condition of matters, however, seems never to present itself in nature.

Experiments such as these made in the laboratory on water films are in the highest degree unsatisfactory. Since I have begun them I have found this surface film of water to be far more delicate and variable than I had previously any idea of, and find it almost impossible to get it in a uniform condition. If the experimenting vessels are not cleansed with something to destroy the last trace of soap used in washing off the oil, if the vessel or the water is touched with the fingers or exposed for any length of time to the air of the laboratory, changes take place in the surface tension. It therefore seems that more satisfactory experiments might be made on large sheets of water. As yet I have been unable to do anything in this direction except one experiment, which, on account of the smallness of the sheet of water, may not be of much value.

The object of the experiment was to see if the wind communicated less horizontal motion to the surface water under an oily than under a clean film, which would be the case if the wind has a less grip or bite of oily than of clean filmed water. It will be observed here that I leave out of consideration any question as to a possible slipping of the oily film over the water, without dragging the water film underneath along with it. If there is any depth of oil, its upper surface cannot slip over the lower more easily than the same depth of water could, as oil is more viscous than water, though we might imagine the bounding surface might prevent the formation of eddies and the deepening of the motion; but we have seen from the experiment with the jet of air on water in a circular vessel, that there is no evidence of any slipping forward, as the body of water underneath takes up the same amount of motion whether the surface is oily or not.

In the experiments made on the small sheet of water, the rate of motion communicated by the wind to the surface water was tested by means of small circular floats 9 cm. diameter and 4 cm. deep. The floats were submerged 2 or 3 m. and only a thin stem projected above the water. Two of these floats were dropped into the pond near that end from which the wind was blowing, and at some distance

apart, at right angles to the direction of the wind. These floats were allowed to drift to the opposite end of the pond to see that the rate of motion was the same at both sides. Some oil was now poured over the water at one side, and other two floats started over the same routes as the first two. It was found that the two floats still travelled at the same rate, that oiling had not perceptibly altered the rate of motion. We might almost have expected a different result, on account of the waves on the clean water affording a better catch to the wind, but possibly this advantage might be lost by the eddies and irregular motions resulting from the waves.

I do not place any great reliance on the accuracy of these experiments, and the last one is evidently on too small a scale; yet I think if the effect of oil on troubled waters is due to its reducing the grip of the wind, the reduction would require to be very great, so great that there would have been some evidence of it even in these imperfect experiments.

There is, however, another consideration which indicates that the oil does not produce its effects by reducing the friction between the air and the surface of the water. Oil itself when exposed to wind is driven into waves very much as water is. It may be that the waves are not so marked in oil as in water, but this is chiefly due to the greater viscosity of the oil. This was seen in some experiments made on a small scale for the purpose of observing the effect of wind on a body of oil. For this purpose two shallow vessels about half a metre square were placed in an exposed part of a field, where the wind could blow freely over them. One vessel was filled with oil, and the other with water as a standard with which to compare the movements of the oil. It was observed that if the oil was thick and viscous there was but little effect, and scarcely any surface circulation produced; and it required a strong breeze to drive the oil into waves. But with paraffin oil, which is thin and mobile, the result was very different; it seemed more easily driven into waves than even water. This was probably due to the oil having a less specific gravity than the water, but I think the comparatively greater agitation observed in the oil was partly owing to the water surface not being quite clean, on account of the paraffin vapour which could not easily be prevented from condensing upon it, so that the water was not so easily driven into waves as it ought

to have been. When a little of the paraffin oil was put on the surface of the water it made it much quieter than the body of oil.

When we pour a little oil on a wind-driven surface of water, the effect is so marvellous, the smoothing of the waves is so instantaneous, that the imagination is carried away, and we at once attribute to the oil some wonderful property, though we may not understand what that property is. When, however, we examine its action and consider what is taking place, we see that it is not doing, it is preventing something which previously took place, and we are driven to consider what it has prevented. In fact, we are driven to examine how the wind gives rise to waves. It will therefore be necessary for us, before saying anything about the effect of oil, to examine how wind acts on the surface of water, and gives rise to waves; we shall afterwards better understand the effect of oil.

The upper surface of water, where it is in contact with the air, is covered with a film having a well-known and definite tension. The tension of this film is always in a state of equilibrium, and the slightest stress acting on a part of it causes the surface to move in the direction of the strain. When a part of the film moves, new film or free surface is formed in the rear of the moving area, and covers the water which was previously covered by the displaced film, while the film in front of the moving film is diminished in area, part of it being absorbed by the water. *No work is required to develop this new film, as the work done by the contracting part of the film in front is equal to the work spent in developing the new film in rear of the moving area.* The result of this is, that the slightest stress acting on the surface of the water determines a movement of that surface, its motion being in no way checked by the surface tension.

Suppose, now, the wind to blow over the surface of a sheet of water, which, for the present, we will suppose to be quite motionless, and for clearness let us suppose further that the wind strikes the water at only one place. The result is that the surface film where the air strikes is blown forwards, and in sliding over the water it produces waves, one set of waves being produced in front of the moving film, and another set produced by the moving film being raised in the act of being driven over the water underneath. Now if,

instead of supposing the wind to act at only one place, we consider what actually takes place in nature, namely that the wind strikes the surface of the water at all points, but more strongly at some points than at others, on account of the eddies produced in the air in its passage over the resisting water, it is evident under these conditions that certain parts of the surface film are more powerfully urged forwards than others, and the water yielding to this unequal action is driven into a series of waves, having a gradually accumulating effect. This effect is intensified by one side of the wave being thrown up into such a position that the wind acts more powerfully on it than on the other side, or than on a horizontal surface.

Let us now look at the action of the same water surface, but over which there has been thrown a film of oil. The surface has entirely changed its character. *New free surface or film cannot now be developed without the expenditure of energy.* If we try to move forwards one part of the surface, we find its motion is resisted by the tension of the surface behind it increasing on account of the removal of the oil, and the tension in front of the moving area does not increase but diminishes. The forward movement of the film is therefore checked. Suppose now the wind to blow over such a surface, the parts where the wind strikes strongest will tend to move forwards, but will be unable to do so on account of the increasing tension behind and reduced tension in front. Further, the parts upon which the wind strikes least are drawn forwards by the greater tension in front of them and behind the parts tending to move most quickly, and where the wind has developed an increased surface tension. The result of this is, that the wind cannot drive forwards *isolated patches of film* or surface so as to cause waves, but the whole of the surface is caused to advance at nearly a uniform rate, and the formation of waves is thereby prevented.

In illustration of these points the following experiments were shown:—Two large shallow rectangular vessels with parallel sides were prepared. Both vessels were filled with water, and over the surface of one was put a little oil, the other being kept clean. Narrow strips of paper, about 2 or 3 cm. broad, were cut to such a length that they would when expanded by the water be slightly shorter than the breadth of the vessels. One of these strips of

paper was put across the middle of each vessel. For the purpose of moving these papers over the surface of the water two threads were previously attached to each of them near their ends. Taking first the vessel with the clean surfaced water, the paper strip was by means of the threads moved into its position right across the middle of the vessel. It was shown that the paper strip could be moved backwards and forwards over the surface of the water, with the very slightest expenditure of energy, the film not in the slightest degree resisting the movement, the free surface or film in front contracting quickly and pulling as strongly as the new film which was developed in the rear. It was further shown that after the paper strip had been moved backwards or forwards into any position, it remained where it was put.*

Turning to the oily surfaced water, it was shown that the movement of the paper strip on its surface was resisted, the threads by which it was moved becoming tightened when it was dragged from its original position; and further, that when the tension was discontinued the paper returned to the place from which it had been moved. It did not matter whether it was moved backwards or forwards, it always returned to its original position, so long as no surface film was allowed to pass round the ends and get to the other side of the paper. The tension on the threads in these experiments represents the resistance which an oily film offers to the forward movement by the wind of isolated areas of surface film.

This resistance is not, however, the most important effect of the oil. It is, so to speak, the secondary effects that are most powerful in checking the formation of waves. On oily surfaced water the forward moving area reduces the tension in front, and causes the film there to advance on account of the greater tension in front; it also increases the tension behind, and so causes the film in the rear to be drawn forwards, and the irregular film advance which takes place in clean water is converted into a uniform and regular advance by the oil. This was illustrated by the arrangements used in the previous experiments. A small piece of paper to act as a float to

* This was found to be an excellent test of the cleanness of a surface film. If there is the slightest impurity on the surface it gets collected in front of the strip, and the paper cannot be moved quite to the end of the vessel without meeting with resistance.

show the movements of the surface film, was dropped on the clean water and near the long narrow strip of paper. The long strip was now moved away from the float, when it was seen that its movement had no influence on the float, as it remained in its original position, and further, the float did not move when the strip was moved towards it. The long strip might be moved in any direction, but the small piece of paper had no tendency to move till it was almost touched by it. The reason for this want of sympathy, so to speak, between the two pieces of paper is due to the surface tension being everywhere alike, and free surface appears and disappears without any disturbance of the surface tension.

When the same experiment was repeated on the oily water the result was very different. There was now a bond of union between the two pieces. If the long piece was drawn away the small piece followed it, if moved up to it the small piece receded from it These movements of the float were pointed out to be the result of the disturbance produced in the surface tension by the movement of the strip. The forward movement of the strip causes the oily film in front to become thicker, its tension therefore becomes less, and it tends to expand forwards, or rather is drawn forwards, by the thinner film in front, and the free surface which is developed in the rear of the strip is rapidly covered by the advance of the oily film which brings with it the paper float. It was shown from this that the forward movement by the wind of isolated areas of oily film was not only resisted, but that their forward movement gave rise to forward movements of the film, both in front and in rear of them. From these experiments it will be seen that a clean water surface acts towards the horizontal force of the wind as if it had no surface tension whatever, whereas an oily film acts very much as if the water was covered with a thin skin of india-rubber. Or the stability of a clean water surface might be compared to that of a perfect sphere on a perfectly horizontal plane, and the stability of an oily surface to that of an egg on its side.

The effect of this regulating influence of the oil on the surface tension may be illustrated in another way, which shows that the uniform rate of advance of the surface film produced by the oil prevents the formation of waves or ripples. If the long narrow strips of paper in the previous experiments are moved quickly over

the surface of the water, the following effects are seen. On the clean water, the advance of the strip gives rise to a series of very evident and well-marked waves or ripples in front of it, whereas on the oily surface no waves are formed. The film is seen simply to contract in front of the moving paper. In order to regulate the motion of the strips in the different experiments, a convenient arrangement is to attach to a pendulum the threads which are fixed to the paper strips, and, by drawing the pendulum and strip aside to the same amount in each experiment, we can regulate its drag on the strip with considerable precision. If we wish to compare the effects of equal amounts of energy spent in each case, so as to get results corresponding to equal blasts of wind, then the pendulum should be light; and if we wish to see the effects of equal rates of motion the pendulum ought to be heavy.

When we examine the surface of a sheet of water under the action of the wind, we observe that the floating bodies on its surface are all moving forwards—all are carried forwards by a surface current, but a closer examination of the smaller bodies lying close to the surface shows that the advance of the surface film is a jerky one; one part of the surface advances quickly, then stops, then another part gets into rapid movement, and the general appearance is that of a patchy and irregular advance of the surface film. With oil on the surface all this is changed; the floating bodies are all now seen to be hurrying forward at a nearly uniform rate, the oil having entirely checked the patchy and irregular advance which gave rise to waves.

Paradoxical as it may at first sight appear, it is nevertheless true that the weakening of the surface film by the oil is a source of strength to the surface of the water, and enables it to resist the action of the wind. The oil, in fact, makes the surface film inextensible to small strains, and so regulates the action of the wind that waves are prevented, and no effect produced save a nearly uniform sliding forward of the surface.

Supposing the explanation here given to be true as regards the formation of small waves or ripples, yet a cause so small seems at first sight quite inadequate to explain so wonderful an effect as that of oil on a stormy sea, and I can easily imagine the question being asked, What effect can this very weak resistance of the surface film

have on the mighty energy of an all but irresistible ocean wave? They indeed seem to have but little relation to each other. Before coming to any conclusion on this point it will be necessary for us narrowly to examine what really is the effect of oil on already formed waves.

Let us therefore examine any small sheet of water over which there is passing a series of well-formed waves, and see if the explanation we have given of the formation of small waves or ripples applies here to the effect of oil. As we look upon the waves as they pass us, we observe that their surface is very far from being smooth; on the contrary, a regular series of waves are being formed by the wind on the surface of the large ones. These waves are small at the bottom of the large waves, and grow in size as they approach the top. In fact, the wind is repeating on the waves very much the same process as when it first begins to blow on calm water. This action on the large waves is, however, infinitely more rapid than on the calm water, as the wind is blowing with far greater violence than ever it does on calm waters; and further, the slope of the surface of the water on large waves being towards the wind, causes its action to be much more powerful than on a horizontal surface. Now, the breaking of large waves is very evidently connected with the formation of these smaller ones which form on them, and grow in strength towards their tops, where they form crests and break, thereby adding dangerous qualities to the wave.

We have already seen that oil prevents the formation of small waves on calm water; it will therefore prevent the formation of small waves on the surface of large ones, and will thereby prevent the formation and breaking of their crests. In order to test whether this conclusion is correct or not, let us again examine the surface of the small sheet of wind-driven water, and, while watching the waves as they glide past, let us pour over them a little oil. At once a change takes place; small waves no longer form on the already made waves, the latter simply continue on their course smoothed and rounded on their surface. We see that the oil by precluding the formation of small waves, has prevented the roughness and the pointed crests which previously formed on the waves and which break when the wind is sufficiently violent. Further, it seems probable that the smoothness of the large waves, produced by the

oil preventing the formation of small waves on their surface, must not be neglected, as it will reduce the bite or grip of the wind, and thereby reduce its action on the already formed waves.

Carrying out this process of reasoning, we see how the great waves of the ocean are increased and made dangerous by exactly the same process which we have seen in operation in smaller ones, only intensified and made more dangerous by the greater surface of the large waves, while the oil, by preventing the formation on their surface of smaller waves, hinders the development of dangerous crests. That oil has no other effect on the great waves of the sea is confirmed by the experiments made at Aberdeen. I am informed by Mr Smith, the harbour engineer, that there was no perceptible lowering of the waves after the water was covered with oil. Its action was simply to smooth over the waves and prevent them from cresting or breaking, an effect of great importance and value in making the entrance to the harbour safer during stormy weather.

It will be observed, according to the explanation here offered, that oil has no power to calm waves; it simply acts by preventing their formation and growth in certain ways. The resistance to extension offered by an oily film will also have, no doubt, a slight effect in checking the up and down motion of the water, but the practical effect of this resistance must be very small and quite unappreciable.

It may be as well for us to note that the general question of the growth of waves has not been under consideration here, our attention having been entirely confined to the effects of surface tension on their birth and development.

Properly to understand the vast importance of so small a cause as the slight difference of tension produced by the oily film, we have only to remember that large waves have their genesis in tiny ripples, which by the cumulative action of the wind grow into large waves, and the oil, by preventing the formation of the ripple, strangles the wave in its birth. On the other hand, the perfectly balanced tension of the surface of clean water is as the "letting out of waters," as "the thin edge of the wedge," as the stone detached from the top of the mountain which brings along with it the irresistible avalanche. Prevent the beginning and the disastrous results are obviated.

It might be thought that the difference between the surface ten-

sion of clean water and oily water is too small to give rise to surface currents or film movements of sufficient velocity to produce these effects, and that the film would break, that is, that all the oil would be blown away before the film behind could be dragged forwards. The ease with which the film glides over the water, and the velocity with which one part of the film can drag another is, however, much greater than might at first be imagined. Take the following examples:—Drop some oil on the surface of water; note the extremely rapid spread of the oil. Now, the rapidity of that surface movement is the measure of the power which that particular oil confers on the water of dragging forwards surface film. In fact, the rapidity of that advance is the same as that with which the film can rush forwards in rear of a wind-driven area. That surprisingly rapid movement seems sufficient to perform the duty the theory here propounded lays upon it.

Another experimental illustration, better suited to the lecture-room, is made by taking a small piece of paper, say 10 cm. long by 2 cm. broad, and attaching to the opposite sides of the ends of it two small pieces of camphor. This is easily done with a little bees-wax. If this piece of paper with the attached camphor be placed on the surface of clean water, it at once starts into a rapid motion of rotation, which will be kept up for hours, till all the camphor is dissolved if the vessel of water is large enough. The rapid movement is here due to the tension of the pure water surface on one side of the strip being greater than the tension of the weak solution of camphor on the other. The paper is thus dragged round by the unbalanced tension of the clean surface. Or we may vary the experiment by placing a number of pieces of camphor on one side of the paper. If this paper is placed on the surface of a pond, it will be rapidly drawn over the water.

Take another example of the wonderful effect of this difference of surface tension. Fill two vessels full of water; put a little oil on one of them, then dust some fine powder over the surface of the water in both vessels. The powder must be free from greasy matter—well-burned ashes sifted through fine wire gauze does well. Now direct a jet of air vertically downwards on the surface of the water. When this is done on the clean water, it will be observed that the very slightest possible current of air causes the surface film

and the dust floating on it to move away from the place where the air strikes, leaving a perfectly dustless surface. Repeat the experiment with the oily surface. It will now be found that however hard you blow you cannot drive back the oily surface, and that when the jet of air is sufficiently strong to cause a deep depression in the surface of the water, the dust particles are seen rushing at certain places into the depression and running out at others with a velocity perfectly surprising.

This easy slipping of the surface film may also be seen when the water is in motion and the film at rest. Recently I observed a small stream flowing quickly enough to give rise to slight disturbance of the surface flatness, and yet the surface film was quite motionless. While the stream was flowing underneath, the advance of the surface film was checked by some weeds and grasses forming a floating bridge across the stream. If the surface had been quite clean this would not have taken place, but a film of weak tension had collected in front of the grasses, caused by impurities derived probably from the bed of the stream, and not from the air, as the stream was in the country, and far from towns and factories. The tension of the surface in front being less than that behind, the strain put on it by the under current was not great enough to cause it to be absorbed in front of the floating obstruction. A somewhat similar effect may be noticed when we stir up—not round—a cup of tea and then drop in a little cream. The surface film movements of the oily tea are seen to stop while the tea mixing with the cream can still be seen in active movement. The drag of the tea on the surface film is not sufficient to develop new free surface against the resistance of the increasing surface tension of the cleaner film, and all surface movements are stopped, save circular ones, which do not require the development and absorption of free surface. These surface movements are sometimes stopped by a rigid pellicle forming on the surface, but they are also stopped when no such covering is present.

It is generally recognised that rain and small floating bodies have an influence on the water somewhat similar to that of oil, and tend to calm its surface. In the case of the rain it seems possible that the great amount of free surface added by the drops causes the surface film to expand and act somewhat in the same manner as oil, as we know that water dropped on the surface of water causes

an expansion of the film where the drop enters. There is, however, another way in which these rain drops act. In falling on the surface, the drops mix up the shallow film current—which makes the ripple—with the water underneath, and thus destroy it. Much of the calming effect of rain is, however, no doubt due to the falling of the wind, which generally accompanies rain.

Small floating bodies act on the surface of water in different ways. Professor James Thomson, in a paper * containing his own and Sir William Thomson's observations on "Calm Lines on a Rippled Sea," shows that these calm lines are associated with long sinuous lines of floating bodies, such as leaves, weeds, &c., and they attribute the calmness in part to the damping action of these bodies acting like floating breakwaters, and destroying small ripple undulations. The author of the paper referred to also points out that part of the calmness is due to oily scum or film; he also shows how these floating bodies and scum may be collected in long sinuous lines by the surface currents produced by descending currents due to difference of temperature. These surface currents, coming from opposite directions, bring with them floating bodies and scum, which collect over descending areas or lines. That part of the calmness of these lines is due to the film at the place having a low surface tension produced by some impurity is confirmed by my own observations made under somewhat different conditions. If we examine the surface of a canal when the wind is blowing very nearly straight along it, we see that on the side of the canal towards which the wind inclines to blow, there is a strip of smooth glassy water extending for about a meter from the bank. This smoothness is evidently not caused by the protection of the bank, but is due to impurities on the surface collected there by the wind, as the calm area has a well-marked line of demarcation, and is present when the wind is almost directly along the canal, the other side of the canal having no corresponding calm area.† The calm areas in the canal in the cases

* "Calm Lines on a Rippled Sea," *Philosophical Magazine*, Sept. 1862 (Fourth Series), vol. xxiv. p. 247, and *Proceedings of Philosophical Society of Glasgow*, 15th Feb. 1882.

† I have also observed that rapidly flowing streams when they enter still water often have calm areas in front of them. This calmess seems to be due to the rapid absorption of the surface film of the stream which here takes place, and any surface impurities brought by the stream get concentrated and become sufficiently great to reduce the surface tension.

observed were not due to floating bodies, as scarcely any were present. Further, an examination of water where a number of small floating bodies were present, showed their action to be quite distinct from that of oily scum. Small floating bodies destroy the waves, but wind can ripple or roughen the surface of the water amongst them, whereas oily scum does not destroy waves, but prevents ripples or darkening of its surface.

My observations on the appearance of the canal suggest another way, in addition to the one given by Professor Thomson, in which oily scum and small floating bodies collect near other floating bodies. One evident effect of floating bodies is to check the forward advance by the wind of the surface film of water, and the shallow surface current is thus converted by floating bodies into a deeper but slower current. The result of this is that more surface film with its impurities comes to the floating bodies than goes away. Surface impurities therefore tend to collect in the neighbourhood of these floating breakwaters.

In addition to this action of small floating bodies in destroying waves there is another way in which small bodies, such as ice-spicules, &c., act, and smooth the water by preventing the formation of ripples. Small floating bodies *prevent the formation of* ripples or waves by deepening the current, and so offering a resistance to the rapid advance of any part of the upper film of water. Weeds and grasses lying on the surface of the water prevent the irregular advance of the surface film, by the resistance they offer to the irregular advance of any part of it, and by the drag or pull they exert on the water behind the parts tending to move quickly. Weeds and grasses thus tend to promote uniform rate of advance at all parts of the surface, and thereby prevent the formation of ripples or waves.

It is obvious that all oils will not have the same power to prevent the formation of waves. It is therefore desirable that we should have some information as to the value of different oils or other substances for this purpose. The value of an oil will depend on a number of things, the most important of which are (1) the rate at which the particular oil will distribute itself over the surface of the water. This will depend greatly on the difference of tension between the surface of clean water and the surface of the water covered with the oil. The greater this difference the more

powerful will that particular oil be. The rate of movement will also probably depend on the viscosity of the oil. The value of the oil will depend (2) on the amount of it required to cover unit area. With these two properties will require to be taken into consideration a third point, namely, the market price of the oil. Besides these points, attention will require to be given to the specific gravity of the oil, its solubility in water, and the rate of its evaporation into air.

I have been able as yet to give attention to only one of these points. A few oils have been tested to find the amount to which their presence reduced the surface tension of water. Most of the methods for ascertaining the surface tension of a liquid are not suitable for testing that of an oily film. In the oily surfaced water we have not only to measure the tension of the oil, but also the tensions of the bounding surfaces of the oil and the water. As these combined tensions vary with the amount of oil on the surface, the ordinary methods of testing are not suitable, as they do not admit of uniform conditions.

It may be as well to remark here, that there is not, as many people suppose, a distinct line of demarcation between the surface covered with clean film and that covered with oily film. That is, the oil wherever present does not always reduce the surface tension to the same amount. On the contrary, there is no line of demarcation between the clean and the oily film; the one shades imperceptibly into the other, and the amount to which the oil reduces the surface tension depends on the quantity of oil present. Very little oil gives a very slight reduction of tension, and as more is added the tension becomes less till a minimum is reached, after which no reduction takes place. This condition is indicated by the oil ceasing to spread rapidly. Its movements after this stage is reached depend upon whether the oil is lighter or heavier than water. If lighter, it very slowly spreads itself over the water, its movements being now due to gravity. If the oil is heavier than the water, it collects and forms on the surface depressions, which deepen, and ultimately a large drop of oil breaks away and slowly sinks in the water. The breaking away of these drops forms a very beautiful experiment, and the slowness of the process gives an opportunity of studying some interesting phenomena.

For testing the surface tensions an indirect way of measuring the tension of the surface of water in a vessel was adopted. This was done by finding the amount of pull necessary to raise a flat disc off the surface of the water. The disc in rising brings with it a certain quantity of water, and the amount of water lifted depends on the height to which the disc can be lifted above the surface before the film yields, and, as this depends on the strength of the film, the weight of water lifted forms an indirect way of measuring the strength of the film. The apparatus used consisted of a circular disc 4·5 cm. diameter. In order that this disc might hang horizontally as nearly as possible, it was accurately turned on the end of a metal rod. The upper end of this rod was hung to one end of the beam of a balance. To the other end of the beam was hung a glass tube, inside which was placed a scale with the zero point near the top of the tube. A tall narrow vessel full of water was placed underneath, and so that the tube hung in the water. The tube was loaded with mercury till it just balanced the metal disc with the beam of the balance horizontal, and the tube immersed in the water up to the zero point. In order to get good contact between the water and the metal disc, a coating of plain collodion was put on the disc. After all the collodion solvents had escaped, the apparatus was ready for a test. The vessel with water to be tested was placed under the disc and at the correct height, the beam, when the disc touched the water, being slightly inclined downwards at the disc end. The tall vessel of water was now slowly lowered. As the level of the water gradually went down, the weight of the graduated tube increased. While the level of the water descended, a careful watch was kept to observe at what number on the scale the disc broke away from the water.

The object of using the submerged tube was that it allows of an increase of weight being put on very gradually and without shock.

With this instrument the different readings for the same sample of water always agreed easily to 1 per cent., though they varied 3 or 4 per cent. for different samples if the vessel which held the water was not carefully cleaned.

Owing to the principle of the construction of this instrument, it does not give absolute readings, nor do the readings of the scale represent numerically the relative strengths of the different films, so that

readings got from the different oily surfaces do not correctly represent their relative values. The readings, however, enable us to arrange the different oils in the relative order of their strengths.

A few of the more easily obtained oils were tested with this instrument. In the following table these are arranged in the order of their tensions on the surface of water, beginning with the weakest tensions, or those which would be most powerful in checking the formation of waves :—

Sperm oil.	Anise seed oil.
Linseed oil.	Almond oil.
Rape seed oil.	Paraffin oil.
Cloves, Oil of.	Lubricating oil (mineral).
Cod-liver oil.	Mineral oil.
Olive oil.	

The first few oils in this list are the best, and do not differ much from each other. Cod-liver oil is not quite so good, olive is decidedly less powerful, while the three mineral oils are by far the worst of all, as they reduce the surface tension very much less than the others. The same result was, I believe, got in the experiments at Aberdeen. Mineral oil was there found to be less effectual in calming the waves of the sea than seal or cod oil.

4. The following communication from the Astronomer-Royal for Scotland was read by Professor Tait :—

In case you should not have any better account of it from those who keep hourly, or perhaps continuous, observations, you may like to mention to the Society this evening, on no more than my twelve-hour testimony,—the occurrence of a decided meteor, of meteorology, last night.

The *maximum* outside temperature yesterday about 2 P.M. was 40°·5, and the *minimum* temperature, self-registered, for the night was 37°·0 ; while at 10 A.M. this morning the then temperature was 41°·0, or nothing very different from the day before. And yet for all that, and some time during the darkness of the night, there had been an influx of warm wind, with a temperature of 51°·0 !

It lasted, too, sufficiently long to impress an inside *maximum* self-registering thermometer as well; for while this should not have

read through the night higher than 52°·0, it was found this morning to have marked 61°·5.

One consequence of this has been, that while the snow of last Saturday held its own very tenaciously all yesterday on the top of the Calton Hill, there is not the smallest particle of it visible this morning on any side, or in any nook and corner; while the grass of the hill looks fresher, greener, healthier than it has done through several years past, at the same date.

The present winter began indeed in a very threatening manner with its great snow-storm early in December. But, as I had the opportunity of mentioning in the Registrar-General's return for that month, the appearance would probably be found to be exceptional, rather than characteristic of the whole season: for we were too far advanced at the present time into the *middle* of a sun-spot cycle, to fear any of those thoroughly and throughout severe winters which, according to the Edinburgh Royal Observatory observations, have never occurred but at, or near, the *beginning* of such a cycle.

5. Diagnoses plantarum novarum Phanerogamarum Socotrensium, etc.; quas elaboravit Bayley Balfour, Scientiæ Doctor et in Universitate Glascuensi rerum botanicarum regius Professor. Pars Tertia.

PLUMBAGINEÆ.

87. VOGELIA PENDULA, *Balf. fil.*: fruticosa ramis pendulis; foliis plus minusve spathulatis; inflorescentia diffusa paniculata; sepalorum marginibus membranaceis vix bullatis intus glandulis instructis; corollæ lobis sinu non-mucronulato.

Socotra, in montibus Haghier. B.C.S. No. 411. Schweinf. No. 586.

SAPOTACEÆ.

88. SIDEROXYLON FIMBRIATUM, *Balf. fil.*: arboreum glabrescens ramis rugosis; foliis petiolatis exstipulatis ellipticis v. oblongo-ellipticis v. obovatis obtusis, basi subcuneatis, subtus pallidis; fasciculis sessilibus; pedicellis brevibus validis; calycis lobis suborbicularibus; corolla calyce longiore; staminum filamentis glabris; staminodeis petaloideis obovatis fimbriatis; fructu rostrato.

Socotra, in convallibus prope Kadhab. B.C.S. No. 339.

OLEACEÆ.

89. Jasminum rotundifolium, *Balf. fil.*: fruticosum scandens velutino-puberulum; foliis trifoliolatis, foliolis petiolulatis subæqualibus v. terminali majore rotundatis v. ellipticis obtusis; cymis paniculatis terminalibus; floribus majoribus pedicellatis; calyce truncato; corollæ tubo elongato, lobis 5–6 oblongis; baccis sæpe 2 globosis.

Socotra, in montibus non infrequens. B.C.S. No. 173. Schweinf. No. 649.

APOCYNEÆ.

Socotora, *Balf. fil.*

Calyx brevis 5-partitus basi intus glandulosus segmentis acutis. Corolla late campanulata, tubo brevissimo, fauce squamis 2-seriatis connatis instructa, exterioribus 5 flagelliformibus sinubus oppositis, interioribus 10 rotundatis obliquis per pares lobis oppositis; lobi 5, oblongo-ovati, obtusi, emarginati, ecaudati, antice rubro glandulo pannosi, contorti, dextrorsum obtegentes. Stamina 5 tubo affixa, filamentis validis, decurrentibus, basi dilatatis et inter se squamis connatis; antheræ exsertæ subovatæ, acutæ, circum stigma conniventes non adhærentes, connectivo lato dorso villoso, loculis basi cassis in appendiculas breves rotundatas productis. Pollen granulosum in quoque loculo in massas 2 cohærens. Discus 0. Ovarii carpella 2 conjuncta; stylus validus brevis; stigma dilatatum, vertice depresso-conicum, lateraliter 5-gonum, galeis 5 cinctum et appendicula stigmatica ab quoque angulo pendula instructum; ovula in quoque loculo numerosa. Folliculi lineares divaricatim adscendentes et basi connati. Semina lanceolata trigono-compressa apice comosa; albumen copiosum firmum; cotyledones lineari-oblongæ, rectæ, planæ, crassiusculæ, radicula supera longiores.—Frutex scandens, glaber, crassiusculus, aphyllus. Folia cataphyllaria opposita. Flores solitarii axillares.

Genus monotypicum bene distinctum in tribu Echitidearum inclusum.

90. S. aphylla, *Balf. fil.*: species unica in montium clivis prope Galonsir crescens. B.C.S. No. 327.

ASCLEPIADACEÆ.

91. Ectadiopsis brevifolia, *Balf. fil.*: fruticosa rigida erecta foliis sparsis brevibus sessilibus sæpe fasciculatis oblongis v. obovatis obtusis emarginatis mucronatis v. apiculatis; cymis sessilibus; floribus brevissime pedicellatis.

Socotra, in campis calcareis. B.C.S. Nos. 583, 615.

92. Ectadiopsis volubilis, *Balf. fil.*: fruticosa volubilis; foliis diversis ab forma lineari ad obovatam variantibus subsessilibus sæpe fasciculatis; cymis pedunculatis; floribus breviter pedicellatis.

Socotra, frequens. B.C.S. Nos. 259, 696. Schweinf. Nos. 472 667.

Mitolepis, *Balf. fil.*

Calyx 5-partitus, glandulosus, segmentis oblongis obtusis. Corolla campanulata, tubo brevi, lobis angustis linearibus obtusis contortis dextrorsum obtegentibus. Coronæ squamæ 5, basi fusiformes, apice filiformes, medio tubo corollæ affixæ qua paullo breviores. Stamina prope basin tubi affixa, filamentis liberis; antheræ erectæ, basi stigmati adhærentes, apice conniventes, acutæ, liberæ, dorso glabræ. Pollen granulosum appendicibus oblongo-ellipticis corpusculorum applicitum. Stigma depresso-conicum medio 2-lobatum. Folliculi divaricati teretes striati subtiliter puberuli. Semina comosa.—Frutex erectus multo-ramosus. Folia opposita fasciculata linearia. Flores solitarii breviter pedicellati.

Genus monotypicum Periplocearum *Ectadis* et generibus vicinis verisimiliter affine.

93. M. intricata, *Balf. fil.*: species unica in montibus Haghier crescens. B.C.S. No. 508. Schweinf. No. 651.

Cochlanthus, *Balf. fil.*

Calyx urceolatus, alte 5-fidus lobis longe acutis recurvis, intus basi 5-squamatis, squamis dentatis. Corolla campanulata alte 5-partitus, tubo brevi, segmentis angustis obtusis valide sinistrorsum contortis dextrorsum obtegentibus. Coronæ squamæ 5, tubo corollæ affixæ, breves, validæ, crassæ, apice 2-lobatæ, basi leviter latiores, subcomplanatæ tubo corollæ æquilongae et supra gynostegium conniventes. Stamina intra coronam affixa, filamentis brevissimis distinctis; antheræ

deltoideæ, stigmati adhærentes, conniventes, apice in appendices breves subulatos abrupte reflexos productæ, imberbes. Pollen granulosum, corpusculorum appendicibus linearibus paullo concavis. Stigma late conicum vertice bilobatum; ovula numerosa. Folliculi crassi breves oblongo-ovoidei leves divaricati. Semina comosa.—Frutex alte scandens. Folia opposita glabra. Cymæ in paniculos corymbosos pedunculatos terminales dispositæ. Flores pedicellati.

Genus monotypicum Periplocearum, corolla, coronæ squamis et antheris ab aliis bene notatum.

94. C. socotranus, *Balf. fil.*: species unica in montibus Haghier crescens. B.C.S. No. 525.

95. Secamone socotrana, *Balf. fil.*: volubilis ramis ferrugineo-tomentosis; foliis obovatis; cymis subsessilibus; corollæ tubo intus lineari-villoso; stigmate capitato spongioso; folliculis breviter pubescentibus.

Socotra, in montibus et campis. B.C.S. No. 179. Schweinf. No. 739.

96. Vincetoxicum linifolium, *Balf. fil.*: volubile glaucum ramis flagelliformibus; foliis filiformibus; cymis extra-axillaribus lateralibus longe penduncúlatis; corona 5-fida lobis carnosulis obtusis.

Socotra, in campis frequens. B.C.S. No. 208.

97. Marsdenia robusta, *Balf. fil.*: fruticosa robusta erecta ramulis petiolisque pubescenti-tomentosis; foliis cordatis v. ovatis obtusis; inflorescentiis petiolis brevioribus; corollæ laciniis oblongis obtusis, tubo intus dense villoso; stigmate rostrato obscure lobato; folliculis pubescentibus.

Socotra, prope Galonsir et Kadhab. B.C.S. No. 522. Schweinf. No. 741.

98. Boucerosia socotrana, *Balf. fil.*: ramis tetraquetris marginibus angulato-sinuatis, lobis in spinas productis; corolla atro-sanguinea; corona alte 5-fida; segmentis apice trifidis, lobo medio minimo incurvo, lobis lateralibus erectis subulatis.

Socotra, in campis abundans. B.C.S. No. 524. Schweinf. No. 740.

GENTIANEÆ.

99. Exacum cæruleum, *Balf. fil.* : suffruticosum humile glabrum; foliis sessilibus v. subsessilibus ovatis trinerviis; floribus pentameris magnis terminalibus solitariis v. in dichasia pauciflora dispositis; calycis lobis alatis; corollæ segmentis cæruleis ellipticis; antheris lateraliter ad medium dehiscentibus.

Socotra, in montibus Haghier crescens ad altitudinem supra 3000 ped. B.C.S. No. 403. Schweinf. No. 672.

100. Exacum affine, *Balf. fil.* : annuum erectum ramosum; foliis ellipticis v. ovatis acutis longe petiolatis 5-nerviis; floribus pedicellatis cernuis 5-meris; calycis lobis late alatis; corollæ lobis obovatis violaceis; antheris ad apicem dehiscentibus.

Socotra, in ripis viridibus fluviorum abundans. B.C.S. No. 82. Schweinf. No. 466.

101. Exacum gracilipes, *Balf. fil.* : annuum erectum ramosissimum; foliis lanceolatis acutis petiolatis 3-nerviis; floribus graciliter pedicellatis cernuis 5-meris; calycis lobis anguste alatis; corollæ lobis obovatis cæruleis; antheris ad medium lateraliter dehiscentibus.

Socotra, in locis aridis frequens. B.C.S. No. 84.

BORAGINEÆ.

102. Cordia obovata, *Balf. fil.* : arborea; foliis petiolatis obovatis v. oblongo-obovatis apice obtusis et dentato-crenatis, basi cuneatis, subtus subscabridulis, supra tuberculatis; cymis paucifloris terminalibus; pedicellis validis brevissimis; floribus mediocribus 4-fidis; calyce enervio extus dense pubescente, subfructu cupulæformi glabro; corolla omnino glabra; fructu aurantiaco ovoideo 1–3-loculari.

Nom. Vern. Abēteh.

Socotra, per totam insulam abundans. B.C.S. Nos. 277, 427. Schweinf. No. 379.

103. Cordia obtusa, *Balf. fil.* : arborea; foliis petiolatis ellipticis v. elliptico-obovatis obtusis v. late acutis integris glabris siccitate nigricantibus; cymis pseudo-axillaribus paucifloris; pedicellis validis

brevibus; floribus ignotis; calyce sub fructu cupulæformi glabro; drupa ovoidea aurantiaca 1-loculari.

Socotra, in montibus prope Galonsir. B.C.S. No. 325.

104. Heliotropium (Monimantha) dentatum, *Balf. fil.*: annuum ramulis a collo patentibus; foliis linearibus v. lineari-lanceolatis dentatis hispidis; inflorescentiis laxe ramosis paucifloris; corollæ tubo calyce longiore; styli lobis non exsertis; nucibus glabris.

Socotra, in campis prope Galonsir et Tamarida. B.C.S. No. 40. Schweinf. Nos. 781, 789.

105. Heliotropium (Heliophytum) odorum, *Balf. fil.*: suffruticosum plus minusve scabrido-puberulum; foliis alternis petiolatis oblongis v. oblongo-ovatis basi subcuneatis; spicis conjugatis ebracteatis; fructu bifido, pyrenis bilocularibus bispermis.

Socotra, in montibus Haghier. B.C.S. No. 181. Schweinf. No. 461.

106. Heliotropium (Orthostachys) nigricans, *Balf. fil.*: suffruticosum intricato-ramosum decorticans ramulis strigosis angulosis; foliis suboppositis breviter petiolatis parvis, ab forma elliptica ad formam obovatam variantibus, nigricantibus strigosis; inflorescentiis paucifloris bracteatis; corollæ tubo calyci æquilongo, limbo magno; stigmate truncato vix bilobato; nucibus scabridis.

Socotra, prope Gharriah. B.C.S. No. 581.

107. Trichodesma Scotti, *Balf. fil.*: fruticosum; foliis magnis ellipticis acutis basi angustatis sparsim setosis; floribus magnis in corymbos magnos terminales dispositis; nuculis magnis $\frac{2}{3}$ poll. longis anguste marginatis.

Socotra, in montibus altissimis. B.C.S. No. 438. Schweinf. No. 623.

108. Trichodesma microcalyx, *Balf. fil.*: annuum hispido-asperum; foliis ellipticis v. ovatis, inferioribus petiolatis; floribus mediocribus; calycis segmentis lanceolatis subfructu non auctis; nuculis deltoideis dorsaliter valide muricatis non marginatis.

Socotra, in regionibus altioribus Haghier montium. B.C.S. No. 538. Schweinf. No. 632.

109. Trichodesma laxiflorum, *Balf. fil.*: annuum sparsim

setulosum; foliis ovatis v. oblongo-ovatis, inferioribus petiolatis; inflorescentiis laxe ramosis; floribus parvis; calycis segmentis lanceolatis subfructu non auctis; nuculis obovatis dorsaliter minute tuberculatis margine alatis.

Socotra, frequens. B.C.S. No. 532. Schweinf. No. 788.

CYSTOSTEMON, *Balf. fil.*

Calyx 5-partitus, segmentis linearibus, fructifer auctus nuculas includens. Corolla campanulata, supra staminum insertionem dilatata, fauce nuda ampliata; lobi 5, ovati, acuminati, imbricati, per anthesin patentes revoluti. Stamina 5, medium tubum versus affixa, exserta, filamentis obcordatis expansis inflatis basi annulo villoso cinctis; antheræ oblongo-lineares, longe acuminatæ, erectæ, conniventes, cohærentes. Ovarii lobi 4, distincti, gynobasi parvæ planæ impositi; stylus filiformis erectus, stigmate subintegro; ovula erecta. Nuculæ 4, erectæ, acutæ, angulatæ, verrucosæ, areola basalari. Semina recta; embryo rectus, cotyledonibus ovatis crassis planoconvexis, radicula supera.—Herba canescens, setoso-hispida pilis simplicibus. Folia alterna. Cymæ scorpioideæ terminales, bracteis parvis inferioribus foliaceis. Flores azurei, pedicellati.

Genus monotypicum *Boragini* forsan maxime affine.

110. C. SOCOTRANUM, *Balf. fil.*: species unica montes altos calcareos Socotræ incolans. B.C.S. No. 309. Schweinf. No. 593.

CONVOLVULACEÆ.

111. IPOMŒA (QUAMOCLIT) LACINIATA, *Balf. fil.*: annua depressa radiatim ramosa ramis prostratis; foliis laciniatis pinnatisectis longe petiolatis sparsim pilosis; floribus subsessilibus in axillis solitariis; sepalis exterioribus subtrifidis; corolla angusta; ovario rostrato; seminibus maculosis pubescentibus.

Socotra, in campis arenosis circa Galonsir. B.C.S. No. 100.

112. CONVOLVULUS FILIPES, *Balf. fil.*: suffruticosus inermis ramosissimus ramis scopariis filiformibus strigosis v. subsericeis; foliis linearibus strigosis; floribus longe pedicellatis laxos racemos terminales formantibus; calycis lobis corolla multo-brevioribus; ovario glabro; seminibus pubescentibus.

Socotra, per insulam totam abundanter crescens. B.C.S. No. 116. Schweinf. No. 238.

113. Convolvulus sarmentosus, *Balf. fil.*: subpulvinatus inermis lignosus perennis argenteo-sericeus ramis brevibus basi congestis cum ramulis paucis virgatis sarmentosis; foliis basalibus rosulatis oblanceolatis, superioribus ovato-acutis v. lanceolatis; floribus pedicellatis breves racemos simplices formantibus; ovario glabro; seminibus puberulis.

Socotra, in montibus calcareis ad alt. 1500 ped. B.C.S. No. 302.

114. Porana obtusa, *Balf. fil.*: fruticosa scandens; foliis oblongo-obtusis; sepalis subfructu paullo auctis; corollæ lobis induplicato-valvatis; stylis duobus.

Socotra, inter scopulos apud extremitatem occidentalem campi Kadhab scandens. B.C.S. No. 355.

115. Breweria pedunculata, *Balf. fil.*: suffruticosa virgata incana pubescente-tomentosa; foliis oblongis subsessilibus; floribus valide pedunculatis in axillis solitariis; calyce corolla breviore; ovario hirto; stylis 2.

Socotra, in campis calcareis. B.C.S. No. 158.

116. Breweria glomerata, *Balf. fil.*: suffruticosa nana prostrata lignosa albido-tomentosa ramis congestis; foliis ovatis v. ellipticis subsessilibus; floribus in capitula hirta terminalia confertis; calyce corolla longiore; ovario hirto; stylis 2.

Socotra, in campis prope Galonsir. B.C.S. No. 114. Schweinf. No. 258.

117. Breweria fastigiata, *Balf. fil.*: suffruticosa argenteo-sericea fastigiatim denseque ramosa ramis strictis; foliis approximatis subimbricatis lanceolatis sessilibus; floribus sparsis in axillis subsessilibus; sepalis apice conniventibus corolla brevioribus; ovario glabro; stylo breviter bilobato.

Socotra, in campis calcareis abundans. B.C.S. Nos. 73, 273. Schweinf. No. 349.

SOLANACEÆ.

118. Withania Riebeckii, *Schweinf.*: frutex habitu foliisque *W. somniferæ* sed ab ea differens calyce profunde diviso et fructifero non vesicoso oreque subaperto.

Nom. Vern. Ābab.

Socotra, frequens in palmetis ad Tamarida et Galonsir. B.C.S. No. 32. Schweinf. Nos. 326, 794.

SCROPHULARINEÆ.

119. Camptoloma villosa, *Balf. fil.* : herba perennis villosa; foliis rotundato-cordatis crenulato-dentatis; floribus paucis in racemos terminales breves dispositis; capsula calycem excedente.

Socotra, in locis scopulosis ad 3000 ped. alt. B.C.S. No. 237.

120. Campylanthus spinosus, *Balf. fil.* : suffruticosus intricato-ramosissimus incanus spinosus; foliis minutis crassiusculis linearibus obtusis; floribus solitariis subsessilibus axillaribus; corollæ tubo calyce duplolongiore; capsula oblonga glabra.

Socotra, in campis prope mare abundans. B.C.S. No. 101. Schweinf. No. 261.

121. Graderia fruticosa, *Balf. fil.* : fructicosa; foliis oblongo-ellipticis v. ellipticis minute aculeolatis; floribus breviter pedicellatis racemos formantibus; corolla sesquipollicari; filamentis et antheris staminum glabris.

Socotra, in montibus Haghier ad alt. 3000 ped. crescens. B.C.S. No. 398. Schweinf. No. 634.

Xylocalyx, *Balf. fil.*

Calyx campanulatus, ad medium v. altius 5-fidus, fructifer accrescens lignascens, laciniis angustis. Corollæ tubus vix exsertus, superne ampliatus, paullo incurvus; limbus patens, lobis 5 latis integris subæqualibus 2 posticis interioribus. Stamina 4, didynama, exserta; antheræ liberæ, glabræ, per paria approximatæ, loculis distinctis parallelis rectis, altero cujusque antheræ tenuiore. Stylus filiformis, apice stigmatoso leviter incrassato obtuso; ovula in loculis numerosa. Capsula basi globosa, apice compressa, in calyce aucto inclusa, loculicide dehiscens, valvis integris medio septiferis. Semina numerosa, obcuneata, testa foveolata.—Suffrutex rigidus, lignosus, nanus, minute aculeolatus, siccitate nigricans. Folia opposita, interdum plura alterna, oblonga v. elliptica, integra. Flores in axillis superioribus subsessiles v. breviter pedicellati, 2 bracteolati. Bracteoli calyci adhærentes, proventu lignascentes.

Genus monotypicum tribui Gerardieæ referendum atque *Micrargeriæ* et *Graderiæ* valde affine.

122. X. ASPER, *Balf. fil.*: species unica in locis aridis camporum Socotrensium crescens. B.C.S. No. 111.

ACANTHACEÆ.

123. RUELLIA INSIGNIS, *Balf. fil.*: fructicosa; foliis petiolatis ellipticis v. subrhomboideis obtusis, lamina glabra supra papulosa cystolithifera; floribus axillaribus solitariis; bracteolis calyce viscido brevioribus viscidis; corolla magna; capsula 4-sperma.

Nom. Vern. Ojehit.

Socotra, in montibus Haghier frequens. B.C.S. No. 376. Schweinf. No. 440.

124. RUELLIA CARNEA, *Balf. fil.*: fruticosa dense stellatim tomentosa et viscida; foliis cordatis; floribus solitariis axillaribus; bracteolis calyce brevioribus; corolla magna; capsula pubescente.

Socotra, in campis prope Galonsir. B.C.S. No. 510. Schweinf. No. 714.

125. BLEPHARIS SPICULIFOLIA, *Balf. fil.*: fruticosa nana ramulis lateralibus contractis; folia rigida oblanceolata v. sublinearia rarius subhastata spinosa; floribus solitariis terminalibus; bracteolis calyce brevioribus; calycis lobis integris.

Socotra, in campis. B.C.S. No. 183. Schweinf. No. 442.

126. BARLERIA ACULEATA, *Balf. fil.*: fruticosa non-spinosa fereglabra; foliis petiolatis obovatis v. subellipticis coriaceis aculeatis; floribus axillaribus solitariis; bracteolis calyce brevioribus; staminibus 2; staminodiis 3; capsula obovoidea basi vix contracta 4-sperma.

Socotra, in montibus Haghier. B.C.S. Nos. 399, 408. Schweinf. No. 553.

127. BARLERIA TETRACANTHA, *Balf. fil.*: fruticosa nana glabra ramis lateralibus axillaribus verticellatim tetracanthis; foliis crassis lanceolatis oblanceolatis v. obovatis apice aculeatis; floribus axillaribus; bracteolis pungente-subulatis calyci æquilongis; staminibus 4, 2 brevioribus; ovarii loculis 1-ovulatis.

Socotra, in campis frequens. B.C.S. No. 605. Schweinf. No. 374.

128. Barleria argentea, *Balf. fil.*: fruticosa inermis argentea canescens; foliis lanceolatis v. oblanceolatis strigulosis acutis v. sub mucronulatis; floribus in cymas bifloras axillares pedunculatas dispositis; bracteolis lineari-subulatis calyce brevioribus; stamina 2; staminodiis 2; ovarii loculis 1-ovulatis; capsula rostrata pubescente 2-sperma.

Nom. Vern. Shiramhan.

Socotra, in clivis montium. B.C.S. No. 544.

129. Neuracanthus aculeatus, *Balf. fil.*: suffruticosus incanus ½–1-pedalis ramulis brevibus; foliis linearibus sinuato-undulatis; spicis axillaribus brevibus; bracteis apice lignosis subulato-pungentibus.

Socotra, in campis. B.C.S. No. 502.

130. Neuracanthus capitatus, *Balf. fil.*: suffruticosus incanus nanus ramis elongatis decumbentibus; foliis ellipticis v. obovatis sinuato-undulatis; spicis congestis in inflorescentias capitatas aggregatis; bracteis angustis apice subulato-pungentibus.

Socotra, in campo Kadhab solum repertus. B.C.S. No. 360.

Ballochia, *Balf. fil.*

Calyx 5-partitus, segmentis angustis acutis subæqualibus. Corollæ tubus longiusculus recurvatus extus pubescens intus glanduloso-puberulus, fauce ampla; limbus 2-labiatus, labio postico exteriore oblongo erecto concaviusculo breviter 2-lobato, antico 3-partito segmentis planis inter se subæqualibus lateralibus erectis intermedio intimo patente. Stamina 2 antica perfecta, fauci affixa, labio postico paullo breviora v. sublongiora, filamentis decurrentibus validis complanatis postice cum staminodiis parvis sublinearibus uncinatis subconnatis; antheræ 1-loculares, oblongæ, medio dorso affixæ, muticæ, apertæ late membranaceæ. Discus pulvinatus. Stylus filiformis apice integer obtusus v. brevissime bifidus; ovula in quoque loculo 3. Capsula oblonga, basi in stipitem solidum longe contracta. Semina 4 v. abortu pauciora, compressa, suborbiculata, rugosa, scrobiculata, retinaculis tenuibus fulta; embryo normalis.—Frutices elati v. humiles, lignosi, rigidi, inflorescentia glanduloso-puberula excepta glabri. Folia parva, integerrima, crassa. Flores flammeo-flavi v. flavidi, pedicellati, in axillis solitarii v. dichasia axillaria simplicia formantes. Bracteæ minimæ, angustæ.

Genus species tres includens *Oreacantho* valde affine sed habitu, inflorescentia, corolla et staminodiis recognoscendum.

131. B. AMŒNA, *Balf. fil.* : virgata ramulis albis sæpe subspinescentibus; foliis parvis subsessilibus oppositis v. fasciculatis oblongis obtusis margine revolutis; floribus solitariis axillaribus pedicellatis pedicellis foliis longioribus glandulosis; stylo apice bifido.

Nom. Vern. Misah.

Socotra, in campis Kadhab et Tamarida. B.C.S. Nos. 364, 430. Schweinf. Nos. 648, 700.

132. B. ROTUNDIFOLIA, *Balf. fil.* : subarborea nonnunquam nana ramulis obscure alatis; foliis brevissime petiolatis late ovatis v. subrotundatis acutis v. obtusis margine revolutis subtus albido-lepidotis; floribus in dichasia axillaria dispositis rarius solitariis, pedicellis longis glanduloso-puberulis; stylo apice obtuso integro.

Socotra, in montibus frequens. B.C.S. No. 300. Schweinf. No. 605.

133. B. ATRO-VIRGATA, *Balf. fil.* : erecta ramulis strictis nigris; foliis brevissime petiolatis elongato-oblongis v. oblanceolatis obtusis margine undulatis subtus glaucis; floribus solitariis axillaribus, pedicellis foliis multo brevioribus glabris; stylo apice breviter bifido.

Socotra, in montibus. B.C.S. No. 578.

134. JUSTICIA (GENDARUSSA) RIGIDA, *Balf. fil.* : fruticosa rigida lignosa cano-velutina; foliis minutis obovatis v. oblanceolatis; floribus spicatis axillaribus; bracteolis minutis calyce brevioribus; capsula cana strigulosa.

Socotra, in campis. B.C.S. No. 358.

TRICHOCALYX, *Balf. fil.*

Calyx alte 5-partitus, segmentis angustis linearibus acutis apice subulatis æqualibus. Corollæ tubus extus pubescens, intus glaber, limbo æquilongus paullo incurvus sursum ampliatus; limbus 2-labiatus, labio postico interiore erecto concaviusculo brevissime 2-lobato, antico oblongo patente breviter 3-lobato lobo medio extimo, palato nullo. Stamina 2, fauci affixa, labio postico æquilonga, filamentis leviter arcuatis decurrentibus; antheræ 2-loculares, loculis discretis, altero altius affixo mucronato v. submutico, altero inferiore basi calcare brevi parvo albo appendiculato; staminodia 0. Discus cupu-

laris v. pulvinatus dentatus v. integer. Stylus filiformis apice obtusus minute 2-lobatus; ovula in quoque loculo 2. Capsula oblonga, basi in stipitem solidum contracta. Semina 4 v. abortu pauciora, compressa, suborbiculata reniformia, papilloso-tuberculata, retinaculis obtusis complanatis fulta.—Frutices parvi. Folia integra crassiuscula. Flores sordide purpurei ad extremitates ramorum in cymas densas congesti. Bracteolæ calycis segmentis similes iisque parum breviores. Gibbi 2 pilosi ab extero basi corollæ tubum intrusi.

Genus species duas includens in sectione Justiciearum locatum, *Justicieæ* affine etiamque *Isoglossæ* et *Anisotidi* sed ab omnibus calyce, corolla antherisque bene separatum.

135. T. ORBICULATUS, *Balf. fil.*: ramulis tomentoso-pubescentibus; foliis orbiculatis.

Socotra, in montibus prope Galonsir. B.C.S. 175.

136. T. OBOVATUS, *Balf. fil.*: ramulis glaucis lepidotis pilisque brevibus puberulis; foliis anguste obovatis v. oblongo obovatis.

Nom. Vern. Elhal.

Socotra, in montibus Haghier prope Tamarida. B.C.S. Nos. 428, 541, 597. Schweinf. No. 371.

137. ANISOTES DIVERSIFOLIUS, *Balf. fil.*: fruticosus; foliis plus minusve obovatis; cymis axillaribus v. terminalibus.

Nom. Vern. Elhan.

Socotra, in montibus Haghier. B.C.S. Nos. 506, 576. Schweinf. No. 477.

138. RHINACANTHUS SCOPARIUS, *Balf. fil.*: herba subglabra scoparia ramulis striatis; foliis longis linearibus.

Socotra, prope Tamarida, B.C.S. No. 687. Schweinf. Nos. 448, 783.

ANGKALANTHUS, *Bal. fil.*

Calyx alte 5-partitus, segmentis lanceolatis acutis 3–5-nerviis subæqualibus. Corolla extus pubescens; tubus limbo brevior, incurvus, superne ampliatus, intus basi dense villosus; limbus longe 2-labiatus, labio postico exteriore ligulato truncato eroso recurvo apice spiraliter revoluto, antico subæquilongo recurvo patente lato elliptico-oblongo trifido lobis linearibus obtusis spiraliter revolutis intermedio latiore

intimo. Stamina 2, fauci affixa, labio postico vix æquilonga, filamentis complanatis breviter decurrentibus; antheræ oblongæ 2-loculares sagittatæ, loculis parallelis æqualibus muticis; staminodia 0. Discus inconspicuus. Ovarium glabrum; stylus filiformis exsertus apice breviter bilobatus; ovula in quoque loculo 2. Capsula ignota . . . . .—Frutex. Folia subintegra. Flores flammeo-flavi in spicas longissimas terminales v. axillares dispositi. Bracteæ bracteolæque minutæ ovatæ. Alabastri falciformes.

Genus monotypicum Eujusticiearum ad Africanum *Himantichilum* et Brasiliensem *Schaueriam* relatum sed bene distinctum.

139. A. OLIGOPHYLLA, *Balf. fil.*: species unica in campo Nogad Socotræ crescens. B.C.S. No. 610.

140. ECBOLIUM STRIATUM, *Balf. fil.*; fruticosum ramis striatis; foliis longe petiolatis plus minusve ovatis; bracteis integris pilosis viscidis; bracteolis calyce longioribus; corollæ limbo tubo subæquilongo calyceque duplolongiore.

Socotra, in montibus Haghier. B.C.S. No. 504. Schweinf. No. 652.

Var. MINOR, *Balf. fil.*: omnino minor; spicis longioribus; bracteolis calyce brevioribus.

Socotra, abundans. B.C.S. Nos. 433, 462.

141. DICLIPTERA EFFUSA, *Balf. fil.*: annua diffusa ramosissima subglabra nitida; foliis ovatis longe petiolatis pungente-cuspidatis; dichasiis longe pedunculatis solitariis axillaribus; bracteolis viscidis lanceolatis v. oblanceolatis pungentibus; corolla bracteolis breviter longiore; capsula viscida.

Socotra, frequens. B.C.S. Nos. 117, 566. Schweinf. No. 463.

142. DICLIPTERA OVATA, *Balf. fil.*: annua parva pubescens prostrata; foliis ovatis breviter petiolatis; dichasiis breviter pedicellatis solitariis axillaribus; bracteolis sparsim viscidis; corolla bracteas longe excedente.

Socotra, prope Tamarida. B.C.S. No. 577.

143. HYPOESTES PUBESCENS, *Balf. fil.*: annua parva pubescens; foliis petiolatis ovatis; cymis paucifloris terminalibus v. axillaribus; bracteolis involucri 4 inæqualibus calyce longioribus, exterioribus

majoribus; corolla resupinata, labio postico longe mucronato; capsula pubescente.

Socotra, apud Kischen. B.C.S. No. 509. Schweinf. No. 612.

SELAGINEÆ.

Cockburnia, *Balf. fil.*

Calyx 5-fidus, tubulosus, lobis angustis acutis æqualibus. Corollæ tubus brevis superne ampliatus; limbus 2-labiatus, patens, labio postico 2-lobato, antico parum longiore 3-lobato lobis subæqualibus. Stamina 4, didynama, supra medium tubum affixa, exserta; antheræ versatiles, confluentia—loculares, medio vix constrictæ. Ovarium 1-loculare, 1-ovulatum; stylus apice minute bilobatus. Fruct. ignot.—Frutex incanus ramis diffusis virgatus. Folia alterna, obovata, integerrima. Flores cæsii, parvuli, in spicas breves terminales sæpe compositas dense conferti, singuli in axillam bracteæ sessiles ebracteolati. Bracteæ non involucratæ, anguste lanceolatæ, calyce parum breviores, cum calyce hirtæ.

Genus montoypicum *Globulariæ* valde affine sed ab ea ob inflorescentiam spicatam sine bracteis involucratis et corollæ differentias præcipue separatur.

144. C. socotrana, *Balf. fil.*: species unica montes Socotræ incolans. B.C.S. Nos. 262, 317, 558. Schweinf. Nos. 568, 610.

VERBENACEÆ.

Cœlocarpum, *Balf. fil.*

Calyx tubuloso-campanulatus, membranaceus, 5-costatus costis in mucrones productis, fructifer patens cupularis drupaque brevior. Corollæ tubus cylindraceus, æqualis; limbus patens, 5-fidus, lobis oblongis obovatis obtusis parum inæqualibus, 2 posticis minoribus. Stamina 4, didynama, supra medium tubum affixa, inclusa, filamentis brevibus; antheræ cordiformes, inappendiculatæ, loculis divergentibus. Ovarium integrum, 4-loculare, loculis 1-ovulatis; stylus inclusus apice brevissime bifidus, lobo antico majore stigmatoso, postico erecto levi. Drupa succosa calyci patenti imposita, endocarpio osseo, pyrenis 2 2-locularibus lacuna intermedia separatis.

Semina exalbuminosa.—Frutex pubescens, inermis. Folia opposita, elliptica, crenata, venulis subtus prominentibus. Racemi terminales breves. Flores parvuli in axilla bracteæ minutæ breviter pedicellati, ebracteolati, secus rhachin alterni v. subopposti, approximati.

Genus monotypicum *Citherexylo* Americano generi arcte affine.

145. C. socotranum, *Balf. fil.*: species unica per montes Socotræ crescens. B.C.S. Nos. 299, 520.

146. Clerodendron (Cyclonema) galeatum, *Balf. fil.*: fruticosum fusco-tomentosum; foliis petiolatis ellipticis v. subobovatis; cymis strictis terminalibus; bracteis magnis foliaceis; corollæ lobo postico cucullato.

Nom. Vern. Dunha.

Socotra, in montibus Haghier prope Tamarida. B.C.S. No. 441.

147. Clerodendron leucophœum, *Balf. fil.*: arboreum cortice albo-tomentosum; foliis parvis oblongo-ellipticis; floribus solitariis axillaribus racemos longe pedunculatos formantibus; calyce subfructu patente; fructu cernuo.

Socotra, abundans. B.C.S. Nos. 182, 385.

LABIATÆ.

148. Orthosiphon ferrugineus, *Balf. fil.*: suffruticosus tomentoso-pubescens demum glaber; foliis longe petiolatis late ovatis v. subcordiformibus rarius obovatis obtusis crenatis utrinque puberulis ferrugineis; racemis 6–8-floris glandulosis; corollæ tubo calyce triplo-longiore, fauce nuda; staminibus corolla brevioribus.

Socotra, in montibus abundans. B.C.S. No. 420. Schweinf. No. 518.

149. Leucas (Ortholeucas) virgata, *Balf. fil.*: suffruticosa virgata ramis fulvis; foliis petiolatis plus minusve obovatis v. spathulatis v. subellipticis integris v. superne trilobatis crassiusculis velutino-pubescentibus; verticellastris 3-floris; bracteis calyce multo-brevioribus; calycis dentibus brevissimis.

Socotra, frequens. B.C.S. Nos. 141, 274, 543, 548. Schweinf. No. 343.

150. Lasiocarys spiculifolia, *Balf. fil.*: suffruticosa nana; foliis spiculiformibus v. triaculeatis; floribus solitariis axillaribus.

Socotra, in campis non frequens. B.C.S. No. 261.

151. Lasiocarys flagellifera, *Balf. fil.*: flagellifera; foliis spathulatis v. cochleariformibus cum dentibus 5–7 pungentibus; floribus solitariis axillaribus.

Socotra, inter rupes calcareas prope Galonsir crescens. B.C.S. No. 233.

152. Teucrium (Polium) prostratum, *Balf. fil.*: prostratum ramis incanis; foliis petiolatis oblongis apice truncatis dentatis, basi abrupte contractis, revolutis; floribus in capitula pauciflora dispositis; corolla calyce pubescente duplolongiore.

Socotra, ad basim montium calcareorum prope Galonsir et Tamarida. B.C.S. Nos. 342, 547.

153. Teucrium (Polium) petiolare, *Balf. fil.*: perenne a collo ramosum ramis adscendentibus plus minusve incanis; foliis longe-petiolatis ellipticis, superne serrato-crenatis, inferne integris obtusis, parum revolutis, supra viridibus, subtus incanis; calycis dentibus deltoideis; corolla calycem pubescentem excedente.

Socotra, in montibus prope Galonsir. B.C.S. No. 431. Schweinf. No. 566, 578.

AMARANTACEÆ.

154. Ærua revoluta, *Balf. fil.*: suffruticosa incana parva ramis erectis complanatis; foliis obovatis obtusis alternis revolutis subtus incanis supra demum glabrescentibus; spicis oblongis brevibus ad extremitates ramorum spicatim dispositis; floribus haud nitidis; perianthii segmentis uninerviis bracteolis multo longioribus; staminodiis brevissimis deltoideis.

Nom. Vern. 'Feh.

Socotra, in montibus Haghier. B.C.S. No. 478. Schweinf. No. 558.

THYMELÆACEÆ.

155. Lasiosiphon socotranus, *Balf. fil.*: fruticosus glaber; foliis obovatis v. oblanceolatis glaucis; bracteis involucri coriaceis glabris latis; calycis fauce esquamato.

Nom. Vern. Lēgief.

Socotra, frequens. B.C.S. No. 518. Schweinf. No. 567.

SANTALACEÆ.

156. Osyris pendula, *Balf. fil.* : arborea glabra ramis pendulis; foliis breviter petiolatis alternis lanceolatis v. suboblanceolatis acutis glaucis; floribus dioicis; ♂ dimorphicis in cymas 3–4-floras longe pedunculatas dispositis, plurimis minutis perianthio rotato 3–4-lobato discoque carnoso, paucis majoribus pyriformibus lobis conniventibus; ♀ ign.

Socotra, in montibus Haghier. B.C.S. No. 630.

EUPHORBIACEÆ.

157. Euphorbia (Eremophyton) socotrana, *Balf. fil.* : arborea glabra; foliis magnis breviter petiolatis late obovatis apiculatis; capitulis magnis solitariis terminalibus; involucro glabro, bracteis fimbriatis; glandulis 6; staminibus paucis; capsulis seminibusque pulverulentibus.

Socotra, in montibus convallibusque. B.C.S. No. 464. Schweinf. No. 531.

158. Euphorbia (Tirucalli) obcordata, *Balf. fil.* : fruticosa ramis juvenilibus puberulis; foliis breviter petiolatis late obovatis v. obcordatis crassiusculis; cymis solitariis terminalibus 3-cephalis; involucro extus pubescente, bracteis fimbriatis, glandulis rubris; staminibus paucis.

Socotra, in montibus. B.C.S. No. 268.

159. Euphorbia (Tirucalli) oblanceolata, *Balf. fil.* : suffruticosa ramis glabris; foliis subsessilibus oblanceolatis mucronulatis; umbellis cymosis terminalibus ramulis brevibus, bracteis magnis rotundatis; involucro extus glabro intus villoso, bracteis fimbriatis, glandulis flavis; capsulis glabris; seminibus tuberculatis.

Socotra, in montibus Haghier. B.C.S. No. 639.

160. Euphorbia (Tirucalli) arbuscula, *Balf. fil.* : arborea

carnosa aphylla; cymis terminalibus sessilibus; involucri glandulis 5 concavis substipitatis; capsulis tomentosis; seminibus levibus carunculatis.

Socotra, abundans. B.C.S. No. 207. Schweinf. Nos. 241, 525.

161. PHYLLANTHUS (EUPHYLLANTHUS) FILIPES, *Balf. fil.*: suffruticosus ramis distichophyllis florigeris angulatis apicalibus; foliis oblongis, stipulis scariosis basi nonproductis; floribus monoicis paucis fasciculatis; staminibus 5, filamentis ad medium connatis, autherarum loculis contiguis; stylis 6; capsulis glabris trisulcatis longe filiformiter pedicellatis; seminibus scrobiculatis.

Socotra, in campis rarus. B.C.S. No. 332. Schweinf. No. 615 B.

162. JATROPHA (ADENOROPIUM) UNICOSTATA, *Balf. fil.*: arbuscula resinifera; foliis lanceolatis v. oblanceolatis glaucis unicostatis; stipulis minutis glandulosis; floribus majusculis; staminibus 8; capsulis magnis glabris.

Nom. Vern. Sibrha.

Socotra, frequens. B.C.S. Nos. 13, 89, 137. Schweinf. Nos. 256, 378. Perry.

163. CROTON (ELUTERIA) SAROCARPUS, *Balf. fil.*: arbor; foliis ovatis penniveniis longe petiolatis lamina basi patellari-glandulosa subtus argenteo-lepidota; stipulis subulatis; inflorescentiis pseudo-terminalibus; floribus dioicis; ♂ racemis multifloris, alabastris globosis, staminibus ultra 20; ♀ umbellis paucifloris, stylo bis bifido, capsula dense setigera, seminibus levibus.

Socotra, in montibus. B.C.S. Nos. 298, 318, 640. Schweinf. Nos. 517, 666.

164. CROTON (ELUTERIA) SULCIFRUCTUS, *Balf. fil.*: fruticosus; foliis ovatis penniveniis petiolatis lamina basi patellari-glandulosa subtus argenteo-lepidota; stipulis subulatis; glomeruli florium in spicas dispositi; fl. ♂ supremi subsessiles, staminibus sub 20; fl. ♀ pauciores basales pedicellati, stylo bis bifido, capsula 6-sulcata lepidota lepidibus planis, seminibus levibus.

Socotra, in montibus Haghier ad alt. supra 2500 ped. B.C.S. Nos. 484, 496. Schweinf. No. 621.

165. CROTON (ELUTERIA) ELŒAGNOIDES, *Balf. fil.*: arboreus ; foliis auguste ovatis penniveniis longe petiolatis lamina basi patellari-glandulosa subtus metallico-lepidota ; stipulis inconspicuis : fl. ♂ ignotis ; fl. ♀ in umbellas dispositi, stylo bifido, capsula lepidibus umbonatis dense vestita.

Socotra, in montibus Haghier infrequens. B.C.S. No. 492.

166. CROTON (ELUTERIA) SOCOTRANUS, *Balf. fil.*: fruticosus; foliis penniveniis petiolatis bidentibus ab parvis ellipticis v. obovatis ad formas oblongas ovatas variantibus lamina basi patellari-glandulosa, pagina utraque pilis stellatis sparsim vestita; stipulis obsoletis; floribus pedicellatis in umbellas unisexuales terminales dispositis; staminibus ultra 20 ; fœminei floris petalis linearibus ; stylo bis bifido ; capsula dense pilis setosis penicillatis vestitas ; seminibus levibus.

Socotra, frequens. B.C.S. Nos. 1, 278, 494. Schweinf. Nos. 449, 798.

167. CEPHALOCROTON SOCOTRANUS, *Balf. fil.* : fructicosus ; foliis ad extremitates ramulorum lateralium contractorum sæpe fasciculatis rotundatis v. obovatis subintegris penniveniis; fl. ♀ sepalis integris.

Nom. Vern. Than v. Tehn.

Socotra, in montibus altissimis et in campis maritimis. B.C.S. Nos. 391, 633. Schweinf. Nos. 430, 544, 797.

168. TRAGIA (TAGIRA) DIOICA, *Balf. fil.* : volubilis lignosa urens ; foliis oblongo cordatis grosse dentatis pilosis et hispidis : floribus dioicis ; ♂ 3-meris ; ♀ calyce 5-lobato, lobis palmatim 5-fidis subfructu ampliatis et induratis, laciniis linearibus hispidis ; ovario hispido ; stylo fere ad basin trifido, segmentis revolutis.

Socotra, per montes abundans. B.C.S. Nos. 366, 626. Schweinf. Nos. 360, 479.

URTICACEÆ.

169. DORSTENIA GIGAS, *Schweinf.* : caulescens caudice crassissimo carnoso ramoso ; foliis oblanceolatis bullatis; receptaculo orbiculari margine 6-8-radiato.

Socotra, inter rupes ad montes. B.C.S. No. 638. Schweinf. 737.

170. Ficus (Urostigma) socotrana, *Balf. fil.*: arborea ramulis pubescentibus; foliis rotundato-cordatis molliter pubescentibus 5-nerviis utrinque alterne 5-8-costatis; stipulis villosis; hypanthodiis obovatis pubescentibus; achæniis ovoideis levibus perianthio membranaceo inclusis.

Nom. Vern. Tuk.

Socotra, abundans. B.C.S. No. 283. Schweinf. No. 414.

ORCHIDEÆ.

171. Habenaria socotrana, *Balf. fil.*: glabra caule gracili; foliis membranaceis oblanceolatis v. oblongis; racemis elongatis floribus distantibus; bracteis ovario brevioribus attenuato-acuminatis; sepalis petalisque obtusis; labello 3-partito lobis linearibus calcare gracillimo ovario longiore.

Socotra, in montibus prope Galonsir. B.C.S. No. 315.

DIOSCOREACEÆ.

172. Dioscorea lanata, *Balf. fil*: volubilis caule tereti piloso; foliis cordatis v. rotundatis v. reniformibus apice spinoso-mucronatis 7-9-nerviis subtus lanatis; spicis solitariis axillaribus; fl. ♂ glomeratis, staminibus 6, ovarii rudimento depresso triquetro; fl. ♀ solitariis, capsulis pubescentibus.

Socotra, in montibus Haghier. B.C.S. No. 482. Nimmo.

AMARYLLIDEÆ.

173. Hæmanthus grandifolius, *Balf. fil.*: glaber et immaculatus; foliis magnis sæpe $1\frac{1}{4}$ ped. longis $\frac{3}{4}$ ped. latis ovatis v. elliptico-ovatis acutis basi parum attenuatis v. plerumque rotundatis v. rotundato-cordatis margine vix undulatis tenuibus delicate venulosis, petiolo $1-1\frac{1}{2}$ poll. longo non vaginante.

Socotra, in montibus Haghier prope Tamarida. B.C.S. No. 194.

LILIACEÆ.

174. Aloe (Eualoe) squarrosa, *Baker* : caulescens caudice simplex; foliis parvis laxe dispositis lanceolatis patulis maculatis apice recurvatis aculeis marginalibus magnis crebris deltoideis; scapo brevi simplici ancipiti; racemo simplici cernuo; pedicellis brevibus ascendentibus bracteis lanceolatis; perianthii cylindrici tubo brevi; staminibus inclusis; stylo exserto; capsula parva.

Socotra, in montibus calcareis prope Galonsir infrequens. B.C.S No. 282.

GRAMINEÆ.

175. Eriochloa vestita, *Balf. fil.*: omnino molliter pubescens rigide ramosa; foliis crassiusculis rigidis brevibus; racemis paniculi 6–8, spiculis compressis ovoideis; glumis vacuis villosis pungentibus, glumis fertilibus muticis.

Socotra, in campis calcareis prope Galonsir. B.C.S. N. 574.

176. Panicum rigidum, *Balf. fil.*: cæspitosum ramis decumbentibus radicantibus ad nodos villosis; foliis brevibus rigidis ad apicem vaginæ villosis; paniculis laxis ramis ramosis plerumque glabris, spiculis omnibus pedicellatis; gluma extima brevissima, glumis interioribus 2 subæqualibus 5-nerviis glabris obtusis, gluma florali levi obtusa.

Socotra, prope Galonsir et Tamarida. B.C.S. Nos. 130, 561. Schweinf. No. 346.

177. Rhynchelytrum microstachyum, *Balf. fil.*: vix pedale plus minusve puberulum tenue; paniculi parvi spiculis $\frac{1}{5}$ poll. longis; glumis secundis et florentibus tertiis apice bifidis lobis rotundatis, aristis glumis vix excedentibus.

Socotra, apud Galonsir et Tamarida. B.C.S. Nos. 124, 254. Schweinf. No. 467.

178. Lepturus tenuis, *Balf. fil.*: cæspitosus breviter repens tenuis; foliis angustis linearibus glaucis longis piloso-puberulis; spicis compressis; gluma vacua solitaria plurinervia florenti gluma et palea duplolongiore; stipite glumam minutam hyalinam gerente.

Socotra, in campis orientalibus insulæ. B.C.S. No. 572.

Ischnurus, *Balf. fil.*

Spiculæ 1-floræ in spica simplici ad excavationes rhacheos compressæ solitariæ, alternæ, sessiles, rhachilla brevissima supra glumam inferiorem articulata ultra florem in stipitem brevem plerumque florem imperfectum gerentem producta, flore hermaphrodito. Gluma infima vacua, rhachi opposita, brevis, rigida, oblonga, truncata v. obtusa, basi incrassata tumida, 8-nervia, margine membranacea; florens æquilonga, membranacea, trinervia, apice obscure trifida ciliata; palea æquilonga, membranacea, 2-nervia. Stamina 3. Styli breves, distincti, stigmatibus plumosis. Caryopsis late ellipsoidea, compressa, glabra, gluma paleaque inclusa, libera.—Gramen perenne, nanum v. elatum, cæspitosum, multicaule, foliis glaucis pilosis. Spica terminalis, rigida, tenuis, recta, spiculis parvis dissitis in rhachi alte excavata quasi inclusis, gluma infima vacua semper adpressa.

Genus monotypicum novum Hordeearum bene distinctum sed *Oropetio* et forsan *Lepturo* affine.

179. I. pulchellus, *Balf. fil.*: species unica in locis arenosis apud Galonsir crescens. B.C.S. Nos. 109, 301.

Monday, 5th February 1883.

Professor JENKIN, F.R.S., Vice-President, in the Chair.

The following Communications were read:—

1. On Scientific Method in the Study of Language. By *Emeritus* Professor Blackie.

2. Further Remarks on the Mirage Problem. By Professor Tait.

BUSINESS.

The following candidates were balloted for, and declared duly elected Fellows of the Society:—The Hon. Lord Kinnear; Mr W. Bowman; and Mr R. H. B. Wickham.

Monday, 19th February 1883.

SHERIFF FORBES IRVINE in the Chair.

The following Communications were read:—

1. On Ancient Tenure of Land in Scotland. By Mr Auldjo Jamieson.

I deem no apology due for introducing to the notice of the Royal Society the subject of the present paper. The close and accurate criticism which distinguishes modern scholarship has allied all branches of knowledge in a common scientific system; and the laws which regulate the development of human society are now recognised as being not less inexorable than those of which the operation on material objects is the more frequent theme in this room. To exhume the forms and types of ancient society, to subject them to close analysis, to identify their prototypes and trace their evolution in our modern life is not less a scientific study than to dig out the nodules of remote ages from those ancient records the rocks, and to subject them to that analysis which detects their identity with forms of life still extant. But with this difference in our present inquiry: the forms of existence of which the nodule is the representative have transmitted their characteristics through so great a succession and variety of forms as to make their identity with, or even relation to, any modern type distinguishable in most cases only by subtle processes of analysis; they are themselves callous and dead, and have no direct contact with the life of the present day; but the systems of ancient society have not undergone that process of extinction and disintegration in transmitting their characteristics; it is less in the alembic that decomposes than by the scalpel that exposes, that their characteristics are discoverable; they do touch, and that often closely, the living present, and there is danger therefore that in the search for ancient truth a nerve may be sometimes touched that may send a thrill into living organisms in our modern society, aflame as some of these are at present with fevered sensation and debate.

I must disclaim at the outset all pretence to originality in either my investigations or their results; my object and purpose will be to present in a brief and conventional form some of the more salient

results which recent scientific investigation has reached as to the relations in which men have stood with reference to the soil of this land in the earliest days of which we have a record, and to trace back to these pristine forms such of the main characteristics of our modern land system as derive their origin therefrom. The study of such subjects has of late progressed so rapidly, and the light thrown on the dark records of the distant past by the patient labours and skilful investigation of such scholars as Dr Skene, Sir H. Maine, and others, has been so clear and so searching that the time seems to have come at which it may be fitting for a mere disciple to enter on the task—not perhaps altogether inappropriate to one brought often into practical contact with existing phenomena of the nature we are to consider—of identifying those characteristics of human experience in this relation of life which in the long evolution of society have stood the test of survival as the fittest for the later development of human life.

The task I thus undertake would necessitate at its outset an ethnological sketch of our Scottish land as we now know it; but I will leap over many perplexing difficulties by assuming a general assent to the view that when the curtain rises on its modern history Scotland was thus peopled,—the Lothians, Fife, Forfar, and Aberdeen, with a population almost wholly Saxon; Sutherland and Caithness with a race also Saxon, but largely Danish and Norwegian; and all the rest of Scotland Gaelic, saturated in Galloway with Saxon or Frisian influences, and characterised in the same district by traces of a more ancient race; with fringes of Irish Gaels on the coasts of Argyll and of Danes and Norwegians in the Isles.

I suppose the rough view which most men who thought on the subject at all had, until a comparatively recent period, formed of the growth of society, was its development from a family into the patriarchal form, and then a number of patriarchs combining with their respective families to form a community, a country, or a state. But nothing in this inquiry is now more clearly determined than that the unit of primitive society, and the centre of all archaic land systems was not the family, but the tribe. The family as we know it was a comparatively late creation, and I think we may doubt whether it had any definite place among our own forbears until Christianity lent its sanction to the domestic relations. Commu-

nity of wives unquestionably characterised that system out of which the Gaelic and the Saxon alike proceeded, and contemporaneous therewith was the community of land which was unquestionably the first form of tenure, if that can be called tenure which nobody held. The earliest traces that exist of social life in the past, and all the analogies that scientific investigation has discovered in the more modern types of archaic society which survive, point irresistibly to the conclusion that while individual rights existed and were recognised in personal property, the soil was regarded and treated as the common property of the tribe; and naturally so, while as yet man sought his scanty subsistence in the chase and in the waters, and the untamed earth yielded to him in common with the beasts he hunted only the spontaneous tribute of its wild berries and roots. While it would be affectation to assert anything definite of a state of society which has left behind it so few traces, and these necessarily so indefinite, still one can discern the first germ of right and title in land in the right which the tribe itself naturally came to assert as against other tribes in the region within which it first began to settle; the choice corries of the deer, the favourite pools of the salmon, above all, the dwellings of their dead, would begin to possess an individual value to that tribe which first began to haunt these localities, and other tribes would be taught to reverence what the one tribe had begun to value; and this was probably the dawn of land right and land tenure.

The tribe first emerges with us from the darkness of barbarism at that epoch of its existence when restrained and coerced by the growth of population the nomadic habits of the race began to give place to pastoral life, and man began to assert his supremacy over the brute creation otherwise than by hunting them. When first the tribe or its individual components began to feed cattle the necessity of feeding ground made itself felt, and it is just at that point that economic history really begins; there is no trace of which I am aware of a common estate in cattle. On the contrary everything tends to the conclusion that among the early inhabitants of this land cattle was the form of property over which the individual rights of man was first asserted, and cattle became the measure in and by which other rights and property were appreciated. Cattle was the money of the ancient people with whom we are now dealing, and

was at the same time the measure and token as well as the substance of their wealth.

It is in Ireland that we must seek both the origin of our Gaelic tenure and the only reliable records of its early growth, while the original features of our Saxon system must be sought in the records that survive of the systems of our German ancestry. One important element in differentiating the Gaelic and the Saxon systems was the earlier Christianity of the Irish and Scottish Gaels, an element—that early Gaelic Christianity of ours—so thoroughly distinctive and so full of special influence, which has left deeper and more frequent traces on our national character and habits than those who distinguish only the catastrophes that signalise abrupt revolution can recognise or are likely to acknowledge.

Giving therefore its due precedence to the more ancient system, the land which the Gaelic tribe held when first we can throw any real light upon it had ceased to be the mere grazing ground of the cattle: agriculture of a rude type had begun to be practised, and the land over which the tribe asserted its sway was of four classes—the land appropriated to the dwelling and its immediate surroundings, the land appropriated to cultivation, the land appropriated to pasture, and the land left free for the chase or otherwise unappropriated. This is the pristine and rudimentary form of land tenure and of society based thereon, which must be accepted as the uniform and invariable type which has prevailed over every part of the world in which man has risen above the level of the savage. Not only in Aryan communities of every variety and of all circumstances, but in communities of Mongolian, African, and Polynesian descent. Modified it was of course by climate, and by soil, and by the innate habits of the people; but wherever men have begun to assert their supremacy over the earth and its products we find these four distinct stages of tenure:—first, the homestead with its yard, the only private or separate property of the tribesman; second, the cultivated zone round the aggregated homesteads, the "field" of the robust inhabitant of temperate climes, or the garden of those more bounteous climates where vegetables more than grains are the food of the people; third, in races of a pastoral type the common pasture land; and lastly, in all, the waste or unappropriated—the hunting grounds

perhaps—but always the magazine from which, as it grew, the tribe drew its supply of fresh land for its increasing numbers.

A very pleasing and simple picture of pristine society is thus presented, and one to which it would rather seem that there is an anxiety in some quarters to revert; it is well therefore to dispel delusions and to point out that this typical condition of ancient life existed with us only as an imaginary point from which to measure the advance to more developed systems. The influences which sway mankind now, swayed them in these olden times: the inexorable laws which operate now among the myriad incidents of our modern life operated then with the same force; and it is interesting to distinguish their operation where we can discern the immediate succession of cause and effect so clearly as we can in those simple communities, just as we can best discern the growth of the organs of riper life in the rudimentary forms they present in the lower types of creation.

What then are the influences to which the historian and the social economist attribute the growth and development of our race? Laying aside the influences of religion as operating in a different plane from that in which we are now moving in this inquiry, I apprehend physical energy and money, the active potentiality of brute strength, and the passive and accumulative force of labour and self-denial, of which wealth or money is the result and embodiment—are those forces which have operated and do operate most strongly on human action; the strong man and the rich man, the strong nation and the rich nation are those which dominate, and in our primitive society no sooner has the curtain risen on the simple pastoral scene I have briefly sketched, than the action of the drama begins by the strong man rushing in on the stage—the Saul of the tribe, lofty in stature and bold of heart, to claim the share of the common property due to his superior prowess—and we find the social equilibrium at once disturbed in order to find for this Kingly man his fitting tribute.

Therefore in the Celtic tenure the mensal lands of the king and the lands devoted to his special maintenance were the first to be cut out of the common property; the king had his own share of the lands as a member of the tribe, and he had the mensal lands besides to support his royal state. These mensal lands remained no doubt

still vested in the tribe, and the king had but a user of them for his life or office. Then came the church, and another part of the tribal lands—the ternal—was set aside for it. But an influence more powerful, perhaps because more subtle than even the regal and the religious, operated to disturb the equilibrium—money began to exercise its sway: dealing with the Irish as the oldest type of the Gaelic tenure, we find the share of the annual allotment of land was regulated by the extent of the herd of each member of the tribe;* perfect equality even in these early days was a matter of theory, and was maintained not because men *were* equal, but only until the supremacy of the fittest had asserted itself according to the inviolable law of progress; and as personal property was undoubtedly separate and individual, the thrifty, the skilful, the industrious, would soon become the rich in cattle, and would soon come to have an increasing share of the common arable land, while the pasture was still common to all equally. Thence arose a very peculiar form of tenure; when one of the tribe became so rich as to have more cattle than he could find pasture for on his own allotment, he lent his surplus stock to less careful or less fortunate members of the tribe, who thus became his "*tenants*."†

It is very notable that in this, which we must accept as the most pristine form of the relation between landlord and tenant, the landlord was *required* to contribute the stock as the essential element in the transaction, and the rent was paid not for the land but for the stock; it is evident that the idea of a separate personal possession of the land was very imperfectly developed at that stage in the history of the tribe at which the power of money first began to effect a differentiation between the members of the tribe, and we have the germ presented to us of the relation now so familiar of landlord and tenant.

But this rudimentary differentiation which we recognise in the Irish tribe rapidly grew, and it developed into one of the worst and most fatal, but still essential, characteristics of all early tenures and of all early society; if it contained within it the germ of the landlord and tenant of later days, it contained a germ of more dangerous import to, and more immediate influence on, infant communities.

* Skene's *Celtic Scotland*, vol. iii. p. 142.
† *Idem*, p. 147.

When the richer man contributed only a portion of the stock to a freeman of the tribe who already possessed some of his own, that poorer freeman had to return a third of the value of the stock annually for a specific period; but when the freeman had no stock of his own, he had to give security for the return of the stock lent, and to pay a food tribute, the type and evidence of vassalage, twice a year. The former, the "Saer Ceile," were the antetypes and progenitors of the vassals of later times; and the latter, the "Daer Ceile" or bond tenants, were the antetypes and ancestors of the serfs and servile races, from whom the charity of the church and the chivalry it begot in long years after, and with many a painful effort, struck the shackles of slavery. Dr Skene says:—"With the Saer Ceile the basis was a mutual contract for a fixed period, usually of seven years, by which the chief gave a portion of stock proportionate to the food-rent he was to receive in return, and was entitled along with this to the homage of the tenant during the subsistence of the contract, and to a certain amount of service in the erection of a dun or fort, the reaping of his harvest, and the sluaged or hosting; but the contract would be terminated and the parties to it return to their original relation to each other, either by the tenant returning the stock he had received or the chief reclaiming it. A more permanent connection was formed between him and the daor ceile or bond tenant. Here the ceile placed himself formally under the protection of the chief as his permanent follower by receiving a certain number of seds or cows, by way of subsidy or gift from the superior, and paying him a certain tribute as the price of his protection. As soon as this relation was constituted he received an additional amount of stock in proportion to the food-rent he had to return, in the same manner as in the case of the free ceile. The real distinction probably was, that in the one case the ceile was in a more independent position, and possessed stock of his own as well as a share of the tribe land, besides what he received from the chief. In the other he was dependent upon what he received from the chief for the whole of his stock. When the chief reclaimed his stock from the free ceile, the latter had the option of becoming a bond ceile if he preferred doing so to returning his stock, and the chief was then bound to add the returnable seds to the stock he had originally given, which constituted the relation between him and the ceile as

a permanent dependant. This process, therefore, not only led to the freemen of the tribe being gradually absorbed into the class of the dependants or following of the chief, but placed a powerful weapon in the hands of the latter, by which he could transform his temporary free ceile into permanent and more servile dependants." *

The separate ownership of land by inheritance seems to have resulted in the Celtic tribes at first from a tacit prescription, the precise origin and foundation of which it would be very difficult to determine. The firm hold which from the first each member of the tribe evidently had on his homestead gave to the skilful breeder or the careful tender of his herd a fulcrum no doubt on which he could work the lever of his wealth; and when for three generations a family retained possession of land, that possession became the basis of title and of a right transmissible by the holder to the succeeding members of his family;† thus originated, it would seem almost by accident or intuitively the right of separate perpetual tenure, on which was raised the superior class of territorial magnates—the original chieftains of the septs and clans into which in its later development in Scotland, preparatory to its final extinction, the tribe broke up.

And when that time for its extinction came, when Alexander III. died in 1286, and the fresher, freer, nobler influences of Saxon and Norman life stirred the stagnant system of Celtic society and gave life and vigour to our Scottish institutions, the form which the tribe had assumed in Scotland was this; there was the central figure, the thane, possessing a large part of the lands as his demesne, representing the mensal lands of earlier days, and very large rights of superiority and service from the inferior members of the tribe; over these thanes there held rule more or less defined, and originating in circumstances exterior to the tribal organisation, the earls of the seven provinces, but that rule was less, I apprehend, a matter of land tenure than of personal rule; below the thanes came a class which can best be described as freeholders holding their lands in absolute fee, but bound as the condition of their tenure to give personal service and to pay certain definite and elaborately regulated duties; below them again came a class of free or kindly tenants,

* Skene's *Celtic Scotland*, vol. iii. pp. 172, 173.

† *Idem*, p. 144.

"liberi et generosi," who held portions of land for ten or twenty years, or for life, with remainder to one or two heirs; these were the representatives of the Ceile of the Irish system, for in many cases the landlord provided the stock and implements, and the rent paid was higher in proportion to the value of these steelbow goods, the rent of the land itself being probably a fixed quantity. With these ended the grades of free tenure, but below these came two grades very important to us as interesting historical types:—*first*, the agricolæ or rustici, who held land from year to year on payment of a fixed rent, but were from their tenure of those servile lands themselves serfs; and *second*, another class of serfs by whose forced labour the chief or thane cultivated his demesne, and who were in the strictest sense slaves. All ancient systems of society and of tenure are tainted by this bane of slavery, but the Celtic system seems to have been saturated with it, and it is a lurid light which these two classes of serfdom throw on the expiring system of our Celtic land tenure, a light which, before I conclude, I will seek to throw into some regions where I humbly think its illumination may be salutary.

The whole framework of this Celtic tenure, with all its intricate arrangements of the clans and septs presenting an elaborate system of order and gradation, conforms but little with our notions of the freedom and breadth of the childhood of our race. The Eastern influence in the Celtic church is unquestionable, and the church exercised a paramount influence in forming the infant society of the Celtic race; the same hard and inexorable rule, the same elaborate gradation, the same spirit of exclusiveness, and the same family pride which characterised the Celtic church as it expired before the more vigorous system of the Roman obedience characterised the Celtic tribal development as it too passed from the stage of history. Was it from the unchanging East, that weird museum in which even now the worn out theories of human society seem preserved for our modern study, that the seeds of the disintegration as well as the germs of the development of Celtic society came?

The records of Saxon tenure, if in some respects less interesting than those of Celtic holding, are at least less obscure and indistinct; and the labours of Freeman, Maine, and German inquirers, whose

researches have been summarised with skill in an admirable paper by Mr Morier,* have thrown a vast deal of light on this subject. It is, however, at a comparatively late period of its development that the Saxon tenure can have had much influence on our Scotch land, at a period too when the orderly influences of the Western church had modified considerably its original character, and had prepared it to receive with ready plasticity the more sharply defined features of the Norman mould. The unit of the Saxon system was the "mark," which in analogy with Celtic and other Archaic systems may be described as the heritage of the tribe. Just as in the Celtic tenure part of this mark was held jointly by the whole community as common pasturage or woodland; another section was divided into lots tilled by separate members of the community, but strictly according to fixed rule, and thrown-open to common use so soon as the crop was removed; a third section was divided into small paddocks or holdings immediately adjoining the township. There seems to have been from very early times separate ownership in these last enclosures, and a separate ownership also in the tillage lands qualified by the common use of them for pasture after harvest.

This system has often been referred to as containing the germ of that co-operative system of cultivation that commends itself to many in the present day as the most advantageous. It is perhaps somewhat fortunate that there have remained until a comparatively recent period traces of this system in both England and Scotland, which enable us to appreciate its real effects, and to discern its appropriateness or the reverse to our modern life. One of the most graphic instances of that survival we have thus recorded:—

"The two large pieces of common land called Dolemoors, which lie in the parishes of Congresbury, Week, St Lawrence, and Puxton in Wiltshire, were allotted in the following manner. On the Saturday preceding Midsummer day, O.S., the several proprietors (of the estates having any right in these moors) or their tenants were summoned at a certain hour in the morning, by the ringing of one of the bells at Puxton, to repair to the church in order to see the chain (kept for the purpose of laying out Dolemoors) measured. The proper length of such chain was ascertained by placing one end thereof at the foot of the arch, dividing the chancel from the body of the

* *Systems of Land Tenure*, Cassell, 1870, p. 297.

church, and extending it through the middle aisle, to the foot of the arch of the west door under the tower, at each of which places marks were cut in the stones for that purpose. The chain used for this purpose was only eighteen yards in length, consequently four yards shorter than the regular land-measuring chain. After the chain had been properly measured, the parties repaired to the commons. Twenty-four apples were previously prepared, bearing the following marks, viz., five marks called 'Pole-axes,' four ditto 'Crosses,' two ditto 'Dung-forks, or Dung-pikes,' one mark called 'Four Oxen and a Mare,' one ditto 'Two Pits,' one ditto 'Three Pits,' one ditto 'Four Pits,' one ditto 'Five Pits,' one ditto 'Seven Pits,' one 'Horn,' one 'Hare's-tail,' one 'Duck's-nest,' one 'Oven,' one 'Shell,' one '*Evil,*' and one 'Hand-reel.'

"It is necessary to observe that each of these moors was divided into several portions called furlongs, which were marked out by strong oak posts placed at regular distances from each other, which posts were constantly kept up. After the apples were properly prepared they were put into a hat or bag, and certain persons fixed on for the purpose began to measure with the chain before-mentioned, and proceeded till they had measured off one acre of ground; at the end of which the boy who carried the hat or bag containing the marks took out one of the apples, and the mark which such apple bore was immediately cut in the turf with a large knife kept for that purpose; this knife was somewhat in the shape of a scimitar with its edge reversed. In this manner they proceeded till the whole of the commons were laid out, and each proprietor knowing the mark and furlong which belonged to his estate, he took possession of his allotment or allotments accordingly, for the ensuing year. An adjournment then took place to the house of one of the overseers, where a certain number of acres reserved for the purpose of paying expenses, and called the 'out-let' or 'out-drift' were let by inch of candle.

"During the time of letting, the whole party were to keep silence (except the person who bid) under the penalty of one shilling. When any one wished to bid he named the price he would give and immediately deposited a shilling on the table where the candle stood, the next who bid also named his price and deposited his shilling in like manner, and the person who first bid was then to

take up his shilling. The business of letting thus proceeded till the candle was burnt out, and the last bidder, prior to that event, was declared the tenant of the outlet, or outdrift for the ensuing year.

"Two overseers were annually elected from the proprietors or their tenants. A quantity of strong ale or brown-stout was allowed for the feast, or 'revel,' as it was called; also bread, butter, and cheese, together with pipes and tobacco, of which any reputable person, whose curiosity or casual business led him to Puxton on that day, was at liberty to partake, but he was expected to deposit at his departure one shilling with the overseer by way of forfeit for his intrusion. The day was generally spent in sociality and mirth, frequently of a boisterous nature, from the exhilarating effects of the brown-stout before alluded to."*

But we have, as is well known, in our immediate vicinity in the burgh of Lauder and at Newton of Ayr equally interesting survivals; —that of Lauder especially, where 105 burgess lots are held under a charter of 1502 renewing more ancient charters which had perished, and conferring power on the burgesses and community to break up and plough their common lands. The possession of one of these burgess acres or lots is essential to being a burgess, and only burgesses are members of the Town Council. The burgess acres consist of lots of from one and a half to three and a half acres, but the burgh holds besides a common of 1700 acres, which is thus dealt with. Once in every five or seven years about 130 acres of the common is set off to be ploughed up and cultivated; the part thus broken up is divided into 105 lots, and each owner of a burgess acre is entitled to a lot which is determined by lot. On the rest of the moor such of the 105 burgesses as are residents pasture each fifteen sheep and two cows, and the widow of a burgess pastures twelve sheep and one cow. Here then we have the Lauder burgess with his "homestead" in Lauder, his share of the "arable mark" in his acres, and his share of the "pasture" and "waste" in the moor; and we have the Council of Lauder prescribing to each burgess the kind of cultivation he is to pursue on the lot of the common land assigned to him. Somewhat similar tenures prevailed in Newton of Ayr,† in Crawford in Dumfriesshire,‡ where

* Hone's *Book of Days*, vol. ii. p. 918.

† *Statistical Account of Scotland*, vol. ii. p. 263.

‡ *Idem*, vol. iv. p. 512.

even more primitive rules prevail, and Whitsome in Berwickshire;* and the system of cultivation which this tenure prescribed—by which the holder of each lot had to conform to the general directions of the community—prevailed widely in the run rig system which was so largely the rule a hundred years ago. The parish of Smailholm was all cultivated in that manner, and at Libberton in Lanarkshire, and many other places, this system of agriculture, testifying manifestly to the prior existence of some quasi-communal cultivation, may be distinctly identified.†

And there are some other traces of a regulation which reflects much light on the real nature of this tenure. At Newton of Ayr there were very special provisions as to the succession to a burgess; and it not unfrequently happened that as females were excluded, a lot lapsed by the failure of an heir qualified to take it up; it then reverted *to the Community*, which disposed of it to the most industrious and fit inhabitant of the place. This, if it could be traced in other cases, would be most interesting, for it would connect this old Saxon tenure of ours very closely with its pristine origin in the distant past in the very cradle of mankind—showing as it does that the tribe or commune was still the radical owner of the soil, and the tenure of individuals only accidental—and connecting this tenure of the Lowland village with those tenures of Eastern and some German types where the right of pre-emption is reserved to the community or its members, and with that provision we are all familiar with, whereby at stated periods of jubilee the tribe reclaimed its lost inheritance from private ownership, and the members of the tribe started afresh on a fresh lease from their mother tribe.‡

In the rapid and necessarily very incomplete sketch which I have thus given of the early tenures in this country there are some notable features which challenge observation in these days. The first of course is the trite but by no means unchallenged observation that the very origin and germ of progress and civilisation is the recognition of individual right. Mankind in the mass remained inert and indolent in the dim twilight of the earliest days: it was man that rose to vigour and action and progress when he asserted his

* *New Statistical Account*, vol. ii., *sub voce.*

† *Statistical Account*, vol. iii. p. 217, vol. ii. pp. 98 and 242.

‡ *New Statistical Account*, *sub voce.* See also Fenton's *Early Hebrew Life*, pp. 71–73.

individualism, and when the leaders of men, spurning the dead level of uniform stolidity, became the pioneers for their fellow-men. No progress—no attempt at progress—is discernible during the dim ages when the land owned no separate title; it was only when what for lack of a better word I must call selfishness contributed its ferment to the inert mass of humanity that the individual sporades developed that activity which we call progress, and of which the product is civilisation.

The second observation flows out of the first: the cultivation of the soil, though the oldest of the arts, is still an art itself of which the basis is experience and the spirit is experiment. Even with ourselves those who are the most proficient in the art desire to free our agriculture from the trammels which seem to them to repress and restrain its still nascent capacity; the freedom of culture desired by many is justified on the ground that successful experiment may reveal fresh methods and more adequate modes of culture. But under any conceivable modification of the Saxon tenure progress was impossible, because experiment was impossible and change impracticable. The same uniform rule of culture had to be followed in even the separate tillage lots because all were interested in the common cultivation; every one had to sow the same crop and to cultivate it in the same way, and the fields had to be cleared for the common pasture on the same day; much of the sluggishness of English agriculture may be distinctly traced to the surviving influences of that Saxon tenure which imposed those fetters of iron custom on the cultivation of the soil from which hardly yet have English agriculturalists emancipated themselves. In Scotland the Board of Agriculture in 1798 say:—"In former times there were several commons in which the cattle belonging to different proprietors went promiscuously under one herd or keeper. The arable land also was possessed in alternate ridges, separated by broad balks, on which the large stones were when the indolent husbandman could take that trouble, and was pastured by the cattle after being freed from the crops. Lands thus awkwardly possessed and wretchedly managed, might not improperly be called wastes; and though Acts of Parliament passed as early as 1695, for dividing at the instance of any proprietor having interest, yet no advantage was taken of such beneficial laws till the 1738 or 1739, when the lands were parcelled out among the several proprietors in proportion to the valuation or rate by which they

paid the land tax."* Nor where Celtic customs prevailed can we discern any greater evidence of progress : we have few traces of how the Highlands were cultivated in very ancient times, but when we first begin to acquire definite knowledge there is much to show that the effect of the ancient tenures had been to arrest rather than promote active and beneficial cultivation of the soil.† Time will not permit of my adducing detailed evidence of this—let me call one witness, no unfriendly one, to the past he reverenced or to the Highlands he loved. Cosmo Innes says, speaking of the rental in 1600 of the Gordon estates, which extended from Banff through the heart of the country to the western sea:—"In all that vast estate reaching from sea to sea, and across ranges of mountains now everywhere pastured by sheep and cattle, there is no payment of wool or woollen cloth, nor of hides or skins, nor any amount of sheep and cattle beyond the occasional mart or wedder for the lord's table. In fact there were at that time no cattle or sheep reared in large flocks and herds in our Highlands. The space and pasture were the same as we know them now, but the thousands and millions of sheep which graze them now had not yet taken possession. The first introduction of large flocks of sheep into the Highlands was in the last quarter of last century. Gough the antiquary, writing in 1780, says that Mr Loch's plans for introducing sheep had been 'attended with some success,' and that the sheep promised to thrive very well in the Highlands. But at this time (1600) there were nothing but the petty flock of sheep or herd of a few milk cows grazed close round the farmhouse, and folded nightly for fear of the wolf or more cunning depredators." ‡

The third observation I would make is this, that the admiration and affection for these ancient tenures professed of late appears to be based on the idea that they were of a highly democratic and universalist type ; there can be no greater mistake ; whether we take the Celtic sept and clan or tribe, or look at the Saxon community with its mark and its gemote, we find a system of rigid exclusiveness, an aristocracy in tenure, an oligarchy in government. There was

* See *Antiquary*, vol. iv. p. 101.

† See Burt's *Letters*, vol. ii. p. 34 *et seq.*, for condition of agriculture even in the last century.

‡ Cosmo Innes, *Scot. Legal Antiquities*, p. 263.

originally no doubt a certain rude equality, but it was only "pares cum paribus," and the "peers" were few, the commons were the many. The Celtic tribe was an exclusive corporation to which birth within its own purple was as essential as it was at the Court of the Empire: the Saxon freeholder was an aristocrat of the bluest blood—no base intruder was permitted to share the privileges or the powers to which the freeholder alone was born—it was oligarchy saturated with caste. The essay in which Mr. Freeman identifies the wittengemote, which has been to many the type of popular self-government by landowners of a common estate with the House of Lords, not the House of Commons, forcibly illustrates what I say; but the case of Lauder illustrates it in a startling though a more homely fashion. There there are 105 freemen, and they have successfully resisted the claims of the profane vulgar of that august city to participate in their privileges: one would regret that anything should happen to shatter so interesting a petrefaction and crystallisation of ancient tenure, but a tenure which maintains an exclusive right of 105 persons to appropriate the ancient common property of the "gemote" is not what I should designate as a peculiarly popular system; it is most interesting that these village aristocrats should share the arable mark and feed their fifteen sheep apiece on the common waste of Saxon tenure, as their fathers did in the time of the Maid of Norway; but though history would have lost a graphic illustration it would not seem to me that humanity would have suffered an irremediable loss had the common estate of Lauder assimilated itself to modern tenure and been devoted to the homely function of bringing in water and clearing out the sewage of that ancient, not to say archaic burgh, even if in the process individual had taken the place of communal right.

It is seven centuries since these ancient systems we have been considering have exercised any direct or practical control over the tenure of the land in which we live, seven centuries full of change and of incident, powerful enough even if compressed into a briefer period to have severed any connection which the active life of the present day could have had with the defunct systems of an almost prehistoric age. But while no doubt much pedantry and affectation have been of late exhibited in the attempt to ascribe to these archaic systems an influence on our modern institutions which it

is impossible for the real student to recognise or admit, still we must bear in mind that those feelings and sentiments which affect the relation of man to his mother earth are deep enough to permit the roots of society to sink into them far below the stage on which the prominent drama of history is enacted; that relation underlies the very framework of society itself, and systems which have regulated the relation of man to the earth which bears him and feeds him continue to exercise a powerful influence over his imagination and feelings long after they have ceased to operate on the actual circumstances of his outward life. Nor from the analogy of other sciences need we be surprised if this recent stirring of these substrata of our early society gives birth to strange efforts to revert to ancient types; these efforts are no doubt due rather to individual eccentricity than to general conviction, just as in nature we find occasional specimens of highly developed species which exhibit a sportive inclination to revert to primeval types from which lengthened cultivation has really far removed the whole class to which they belong.

There are, however, not a few side lights which the fitful gleams we get in studying these ancient types of society may throw into the origin and pristine circumstances of those relations which subsist in our own day. For instance, the theory of rent most acceptable to modern economy and most consonant with modern circumstances is that which represents the rent as the share falling to the landowner of the profits of a quasi-partnership, to the capital of which the owner contributes his land and the tenant his stock, his labour, and his skill. Very ancient types of society justify this theory, and in many parts of Europe more subject to Latin influences than we have been it survives in the metayer systems which prevail; but it is on the whole a modern development, and bears abundant evidence of its origin in a state of society much more cultivated than any of those we have been considering. The rent of our ancient tenures was originally in the main personal service, and even when it began to assume the form of money payment it was a pecuniary substitution for such services or for that direct maintenance in bed and board which the king or the chief exacted; and it was always fixed and definite, bearing no necessary relation to the *value* of the land. The foundation of our ancient relation between landlord and tenant was not, I apprehend, partnership but sale; a tenant did not share the produce with his landlord, he bought the

temporary use of his farm for a certain price payable by instalments during the lease; he was more a temporary feuar, or a copy holder, than a tenant in our sense of the term. And herein lies a very important and curious distinction between ancient and modern economy, which is the key to many difficulties; with us, the price of an article and its value are almost convertible terms, but it was not so of old, it was not so not very long ago. Price was *fixed* in the ancient times I speak of by custom, and when we read with wonder of statesmen in even modern times seeking to fix the price of viands by enactment they were only struggling with the idea which in pristine societies fixed *price* by inveterate custom. Even now in India there are districts where the price of shoes for instance is fixed by inviolate custom, and the shoemakers adapt themselves to circumstances not by altering the price but by modifying the quality of their goods; and not very long ago in some European countries the price of the loaf was fixed and its dimensions fluctuated.

Now in England we know that the rent of the land has not even yet borne the same intimate relation to its value it has done in Scotland; the rent which a man's father and grandfather paid before him has lingered there as an almost customary rent different in degree rather than in principle from the really customary rent of the copyhold tenure; and the commercial principle which our modern practice especially in Scotland has introduced of close identity between value and price has in England penetrated with the slowness proverbial to agriculture into the relations bearing on land. I think there may be some of the unsolved problems of this relation upon which the consideration of what I have thus referred to may throw a little light.

Another ancient fact bearing on the landlord and tenant of our modern experience seems worthy of some note; the pristine form of that relation was, as I have already shown, of an alternative character. The tenancy might be one practically of steelbow, in which the landlord supplied stock, implements, and the scanty housing if any; or it might be that by which the landlord sold temporarily the use of his land only, leaving the tenant to supply himself with all that he required for its cultivation. It was this latter form mainly that survived into later times. We have of course no written leases remaining to us of the very early times to which I have been specially referring; but those early leases which do remain entered into at a

date when owing to the inveterate habits of a rural people, the main features of the early contract must have survived, the stipulation that the tenant should supply the houses, &c., required for the proper cultivation of the farm is to be found. In a lease, for instance, so early as 1312* it was stipulated that the tenant should supply suitable buildings for himself and his husbandmen, which were to be left at the end of the lease ; after an interval of two centuries, under the next earliest lease of which I have seen any note, in 1511 the tenant is taken bound to build three onsteads to be inhabited by himself and his dependants under pain of forfeiture ; a crofter is taken bound to build a rood of enclosure for every cow he has on the lands of the principal tenant; and in two cases tenants were taken bound to build houses on their farms, but were allowed to retain a part of their rents to assist them in doing so. These were church lands, and we may be sure these stipulations represent nothing more severe than the usual tenure, but probably the reverse. Now such a system was quite consistent with the idea of a partial or temporary sale of the subject, which was the bare land, not as in steelbow the land equipped with stock and appliances of which the wattled houses of these early days formed probably no very important part; but it was quite inconsistent with the more developed ideas of modern economy basing the lease on quasi-partnership, and was not suited for our modern use with the more important outlays now required for modern agriculture. It is well, however, to discern from these examples that the principle now universally recognised as the best, which imposes on the modern landlord the necessity of supplying all that is required for the full equipment and beneficial cultivation of the farm, or of recouping to the tenant what he may dispense for such purposes, is no exhumation, as has been often represented, of ancient custom or tenure —no reverting to a more generous system long forgotten. Antiquity knew nothing of the kind, or if the steelbow form of lease is to be taken as the archaic type of what is advocated, then the experience of seven centuries and the advance in independence of the agricultural class have demonstrated that that system is unsuitable, for it has failed to survive. It may be less interesting but it is certainly safer, instead of searching for principles and precedents for our present guidance among the archaic systems of the past, to recognise that even the highest forms of these were datum lines from which to

* Innes, *Legal Antiquities*, pp. 263, 264.

measure our own advance. The history of land tenure is the history of progressive emancipation; to represent the changes necessary to adapt it to our advance in economic science and social development as a process of reverting to the spirit of ancient practice is to subvert the teaching of history; it is to the progress, not the retrogression of ideas on this as on other topics that we have to ascribe the advance we have made and are making; it is what is most fit for our modern life that survives, not what may be most interesting or picturesque.

No section of the inquiry into the relation of man to the soil is so difficult of solution as that which relates to the poor, and none to us of the present day is more interesting. If, as seems to be thought by many, there were days in this land in which the poor were not always with us, no wonder longing glances are thrown backward to catch even amidst the darkness of barbarism glimpses of so happy a condition. But a closer study of the facts dispels the illusion; besides the abnormal growth of population to which the Duke of Argyll referred in a recent essay (which is, in my humble opinion, the ablest contribution yet made to the economical treatment of this subject)* there are other elements—two especially—which do not appear to me to have received adequate consideration; if the days to which we have been referring were ignorant of poverty, it was greatly due to these facts, that slavery held its place in their economy, and that the habits of all classes of the people rendered them to a large extent independent of external supply—they were largely self-sufficing.

The nature of the slavery of these remote times it is very difficult accurately to distinguish; it was certainly of at least two distinct forms. There were the serfs, the *nativi*, probably the descendants of an ancient race, often the members of tribes which had been subjugated by stronger neighbours, always attached to the land, and not apparently removable from it even with their assent, and almost certainly not without it. These serfs were slaves in this respect that they had neither in the Celtic nor in the Saxon economy any rights; but if the land held so tight a grip on them, they in turn held a tight grip on the land, and had certainly claims on their lord or owner, though whether these claims were those of an

* See *Contemporary Review*, January 1883.

inherent right to support or proceeded merely from the self interest of the lord himself in the preservation of his property, it is very difficult to say.

But below these there was a class of slaves who were mere personal property; probably orignally captives of war, but latterly in many instances freemen who had been reduced to want, and who sold themselves as a condition of receiving maintenance and prosection from the powerful and rich; and this sale affected their posterity.

While there seems very little doubt that the position of the predial serfs even if originally equivalent to that of slavery became latterly a mere form of tenure of service, and that they had probably to endure none of the degradation of positive slavery, there can be no doubt that it was not so with the other class. Theirs was a slavery from which men fled in horror, and to which they were dragged back in terror and in chains. The early Acts of Parliament abound with evidence of this and with directions for the recovery of fugitives, and even in the 14th century slaves were recaptured, and handed back to their owners under sanction of the law.

These were the poor of the ancient tenures, and we can readily discern why they were so largely dependent on the lords of the soil for maintenance and defence; their gradual emancipation from actual serfdom or slavery followed insensibly on the development of the church and the progress of society, but their dependence on the chief or lord continued, and while they swelled the train of his followers they looked to him for support. This was a burden which speedily began to press on the chiefs in the Highlands, and although plague, pestilence, and famine came largely to their relief, the growth of the population impelled them insensibly into that turbulence and restlessness which distinguish the annals of our Highland life; it is not perhaps so picturesque as one would wish to ascribe the frequency and the fierceness of Celtic feuds to the mean necessities of the larder, but these economic forces were too powerful to be ignored in any veritable history of the clans.

It is very interesting to those who study these ancient forms of life to find extant, or only recently extinct, forms of society possessing all the main features which we have reason to believe characterised these early days in our own country. The practical experience

of men like Sir H. Maine and Sir George Campbell and other scholars who have applied their knowledge of the Aryan races in India to the elucidation of our Scotch archaic history has thrown much light on the subject; but I think a speech made a few weeks ago by Dr Hunter in the council of the viceroy on the treatment of the people of the Deccan is singularly illustrative of the subject I am now treating. "The peasantry of the Deccan," he said, "have been suffering from economic causes sufficient to break the spirits and to ruin the fortunes of any race. Seventy-four years ago, when the Mahrattas and the peasantry of the Deccan passed under our Government, they had five great sources of livelihood. The economic and political changes brought about by British rule have deprived them of four of these sources and left them only one. In the first place, the Mahratta race had, during nearly two centuries, derived a large, although a fluctuating, income from war. Its pillaging invasions of wealthier provinces were reduced to a system of strictly mercantile adventure, which enriched alike the fort of the chief and the cottage of the peasant. For the Deccan hordes were not the accidental product of any single leader, but the natural result of an overflowing peasant population under the guidance of a hereditary administrative caste." I thought I had read this before, and turning to Cosmo Innes's charming essays on our early Scotch life, I found this :—"The power of the chief or *laird* was measured by the number of men he could turn out under arms, and he had every inducement to maintain the full number of dwellings and inhabitants. In summer the people of the glen might exist upon the produce of their pasture lands, and there was a little corn for the beginning of winter, but for the rest of the year they must necessarily have sought sustenance elsewhere. They could not dig, to beg they were ashamed. There was a third alternative, they left their glens and *lifted*."*

Dr Hunter goes on to show how the advance of civilisation has dried up the sources of the former wealth and even subsistence of the Deccan peasantry, and we could tell the same story of our own land; the looms of Galashiels and Hawick have silenced those in the Highland glens, and all the manifold changes that railways and steamers have introduced into the habits of a people formerly so self-contained and self-sufficing have conduced to the reduction of

* Innes, *Scottish Legal Antiquities*, p. 269.

the value of such labour as the Highlands supplied. Lassalle and Karl Marx in their crusade against modern plutocracy have depicted with great force and skill the vast difference which there is between a system of society which is content to supply only its own necessities from day to day and that high pressure of modern life, which, stimulated by capital ever eager and hungry for gain, manufactures on speculation, and anticipates demand by an ever-ready and often over-abundant supply. Lassalle, speaking of the feudal lord of Germany, says:—"Look upon the landed proprietor during the middle ages, the noble lord surrounded by his castles, his manors, his vassals, serfs, and dependants, his allodial villages and tributary towns. Was this man a capitalist? Let no one suppose that people lived on the produce of the land only, which is the crude notion of some people. Production was sufficiently developed, luxury considerable, and the articles of consumption manifold and refined." He then proceeds to give from mediæval writings a description of prevailing fashions in wearing apparel, furniture, and the like, showing the advanced state of fashionable society then and its varied requirements. He shows how all these are provided by the combined contribution of vassalage, by what he calls a "mosaic work of services." Under this system man is no longer a slave, but his will is the private property of another. There is an exchange of services and natural products without the intervention of money as a general measure of value. "The acres of the feudal lord" he points out "are cultivated not only by serfs but with the help of man and beast, by means of villenage more or less reasonable in extent, varying from three days in the week to five or six weeks in the year, according to the position of the feudal dependant." Then again, he says, "put yourself in imagination back to one of the days for collecting the yearly revenue, when the feudal lord receives his dues. Then you will see heaps of corn and barley, chicken and bacon, oxen and swine, eggs and butter, oil, fruits, wax, candles, honey, yea even cakes, bouquets, and *chapeaux de rose*, all contributed by his faithful lieges. The tailors and shoemakers of the small town under his protectorate, remembering the principle *nulle terre sans seigneur*, bring their clothes and shoes which have been made during the week's service they owe him." Similarly he enumerates the various tradesmen and artisans

who are bound to contribute their respective portion of the lord's requirements in natural or manufactured goods; and a long inventory of services rendered to his household by their wives and others belonging to them follows, all to show "that scarcely a want can be conceived which is not provided for by some special obligation in this system of natural services. Even professional men like advocates must give their advice as a duty, free of charge, to the lord of the manor. His amusements even are provided for him by his own dependants free of charge. He is a wealthy man, without the possession of money; for he cannot turn these services or commodities into capital. He avails himself with a vengeance of all these means of enjoyment which are thrown with such profusion around him, and he does it cheerfully without care or worry, and thus is more happy than the rich speculator of modern days whose tranquil enjoyment may be disturbed by a passing thought about the money market as he listens to the music of Beethoven or Mozart. But beyond consuming with enjoyment the feudal lord has nothing. He has no means to multiply his wealth by itself; not money but service was the common bond uniting all the members of the empire among themselves and under a common head.

"By this system of fixed services and mutual obligations no room is left for capitalistic enterprise or industrial progress, the whole process of production receives a stereotyped form, agriculture and the trades run on without change in the same groove." *

The Highland chief of old lived very much as, Lassalle so picturesquely points out, the old feudal lords lived, if upon their people, yet with them and among them; they supplied all his wants, and these supplies and their personal services fulfilled all their obligations. The people had no money, and they needed none; they paid their rent in kind or by service, their necessities were few, and their commerce had not risen above the rudimentary stage of exchange; the chief had no money wherewith to import foreign commodities, and he lived in the rude plenty which his people supplied; when his supplies failed we know how they were replenished. All these influences have told on the poorer class in the Highlands especially, and it is interesting and may be useful to inquire how modern economy has coped with the difficulties presented to it by the extinction of ancient habits and resources.

* *Socialism.* Henry S. King & Co., 1874, p. 73.

To translate the serf and the slave of ancient life into modern language, I would use the word "dependant"; that I think conveys more of the spirit of the ancient relation with its mutual service and protection than the terms of slave and serf, which convey a harsher meaning than probably describes the true nature of the tie which bound the earliest predecessors of the chiefs to those below them. Now, in our modern life, how has this relation adapted itself to modern systems? The chief, though deprived of the services of his dependants, has been forced to maintain and protect them; not in the grand patriarchal manner of ancient times, and with none of their pomp and panoply of war, and with none of their keen zest for raids and marauds; he has to pay poor rates. But translated into the vernacular of our modern life he has no light burden thus to defray. I have taken ten parishes in Inverness, and eight in Ross, of which the gross rental in the one case is £58,000, in the other £64,000; of the £58,000 in Inverness, £15,800 is paid by tenants under £10; of the £64,000 in Ross, £17,500 is paid by tenants of the same class. The poor rates paid in the ten Inverness parishes amount to £6200, in the eight Ross parishes to £8300. I cannot state accurately the school rate, but one of the inspectors in his last report says it varies in one of these districts from 2s. to 6s. 8d. per £. I have taken it at the lowest amount, and we have thus in the Inverness group an assessment of £12,000, and a rental under £10 of £15,800; in the Ross-shire group an assessment of £14,700 a rental under £10 of £17,500. Now I cannot here attempt to determine what precise proportion of that assessment is due to the special necessities of the small tenants under £10, but everyone will admit it must be very large. For the maintenance and education of the poor in these districts the land has to pay annually about 90 per cent. of the nominal rental under £10, and a proportion of course very much greater of the real rental actually drawn. It is safe to say that more than the whole rental under £10 is required to defray the expense of maintaining and educating the poor. It can hardly therefore be said that the survival of the relation between the land and the poor from ancient times, if it has been in many respects painful to those who were the dependants of the old chiefs, has been favourable to the successors of the chiefs themselves—the fathers no doubt ate sour

grapes in the olden time, and the teeth of the children have been set very much on edge by the operation.

But the landlords are not the only survivals of those on whom the poor of the ancient times were dependent; as stated by Mr Innes, and as illustrated by many a stirring tale of old, others besides the landlords were made to contribute to the necessities of the noble peasantry of the glens. When in 1856 and in other years, as now, the successors of the douce provosts of olden times invite us to contribute to relieve the urgent necessities of the suffering Highland poor, they are only putting into modern language the levy their predecessors would have made upon us to pay the black mail the clans would have exacted when their domestic means of subsistence failed, as they have done. At no time within modern history, since population began to grow beyond very narrow limits, have several of the poorer districts of the Highlands been able to supply their own needs; there has never been a time when the plenty of one period has there sufficed to meet the scarcity of another; whether the levy has been by war, or by tax, or by charity, extraneous aid has always had to contribute its quota. As the Duke of Argyll has recently reminded us, nature in old times, when population outgrew its bounds, asserted her inexorable laws by sending plague, pestilence, and famine to clear off the surplus; our modern civilisation has curbed these powers, as well as repressed the social characteristics which accompanied and assisted them, and thus is presented to us the same problem, though within far narrower limits, which is pressing on the Government of India—the growth of a population at a rate far in excess of that in ancient times, bringing on our modern economy and social science burdens due to their own beneficence.

The suggestion so frequently made of late that the poorer cottars and crofters of the Highlands are the inheritors of ancient tribal rights in the land is, as I have already shown, quite fallacious; the relation of dependence in which that class unquestionably stood not only in feudal times to the later lords and chiefs, but in still earlier days to the original freeholders of the tribal organisation, did not permit of their having any rights; the exclusive system of the tribe, the restriction of all rights to the freemen, forbid the possibility of any rights in the land having been held by those who were below that rank; and there can be no doubt that the freemen of the tribe

grew into the chiefs and the lairds, the feuars and kindly tenants of later days, of whom the cottars and crofters are in no sense representatives. Here, again, I would point out how dangerous it is to refer to analogies in those early days without due care in establishing their identity with the modern circumstances they are intended to illustrate. It is a safer course to let these dead systems bury their dead—and to apply ourselves to the careful study of our own social problems by the brighter light of our own social progress. In that light it humbly appears to me that the frequent recurrence of Highland distress is a reproach on our modern economy from which ancient systems were free, however that freedom was obtained. It is foreign to the subject of which I treat to pursue this subject, but this I may say, that dealing with people who have been for ages habituated to be led, to be dependent for guidance on others, to be protected by others, who are only emancipated but not yet free, if our modern system is to fulfil the duties it has inherited from the past, it must supply that initiation and guidance and motive power and influence which of old, under very different circumstances and in very different directions, the chiefs of these people supplied: to parody a well-known aphorism, relief is no cure: it is the proper task of modern economy to show these people the method, to induce them to adopt the measures, and even to supply them with the means to win that independence which is a nobler, and will be a more useful inheritance than any that they claim from the distant past.

I had intended to say something as to the taxation on the land of these ancient days and its relation to our modern imposts, but I have already far exceeded the limits of my paper and must conclude. I have fulfilled my purpose if I have directed attention to, and created any interest in, the salient features of those ancient tenures which are in any way reflected in our present social system; and if I have succeeded in demonstrating that after all it is more as studies and as cabinet specimens than as models that we must regard them; that they were only the nurseries of society, not even its schools; interesting and picturesque no doubt, attractive but deceptive, festooned with the mosses and encrusted with the lichens that adorn the decay while they conceal the defects of hoar antiquity.

Table showing Rental, Poor Rates, and School Rates of certain Highland Parishes, 1881–82.

PARISH.	Gross Rental.	Rents under £25.				Over £25.	Poor and School Rates on Gross Rental.		
		£25–10.	£10–4.	£4–0.	Total.		Poor Rates assessed.	School Rates assumed at 2s.	Together.
	1	2	3	4	5	6	7	8	9
1. Portree, . . £	8,314	1,697	1,454	467	3,618	4,593	1,039	831	1,870
2. Kilmuir, . .	6,119	1,071	1,195	48	2,314	3,736	484	611	1,095
3. Snizort, . .	5,802	674	1,162	202	2,038	3,715	628	580	1,208
4. Diurinish, .	7,702	531	1,697	678	2,906	4,646	481	770	1,251
5. Strath, . .	5,308	366	739	492	1,597	3,587	552	530	1,082
6. Sleat, . . .	4,440	233	440	542	1,212	3,099	481	440	921
7. Barra, . . .	2,217	167	186	483	836	1,345	369	221	590
8. S. Uist, . .	6,680	609	1,874	1,084	3,567	3,018	807	668	1,475
9. N. Uist, . .	5,443	458	1,281	381	2,120	3,152	681	544	1,225
10. Harris, . .	6,141	370	1,014	359	1,743	4,278	665	614	1,279
£	58,166	6,176	11,042	4,736	21,954	35,169	6,187	5,809	11,996
1. Barvas, . . £	3,212	203	678	1,581	2,462	668	535	321	855
2. Lochs, . .	4,671	69	420	1,686	2,175	2,423	855	467	1,322
3. Stornoway, .	14,139	3,106	2,542	2,475	8,123	4,556	2,002	1,413	3,415
4. Uig, . . .	5,229	92	706	732	1,530	3,656	620	522	1,142
5. Lochbroom, .	15,089	498	1,465	1,007	2,970	12,085	2,011	1,508	3,519
6. Gairloch, . .	11,588	493	930	1,096	2,519	9,005	1,158	1,158	2,316
7. Lochcarron, .	5,758	833	574	278	1,685	4,052	359	575	934
8. Applecross, .	4,401	299	619	698	1,616	2,732	751	440	1,191
£	64,087	5,593	7,934	9,553	23,080	39,177	8,291	6,404	14,695

The sum under column 1 includes in addition to Nos. 5 and 6, the rental of land held by school boards, &c.

2. On the Microscopical Appearances of Striped Muscular Fibre during Relaxation and Contraction. By Professor Rutherford.

BUSINESS.

In terms of the Laws, a ballot took place for the following proposed Honorary Fellows:—*As Foreign Honorary Fellows*—Luigi Cremona, Rome; Julius Hann, Vienna; Charles Adolphe Wurtz, Paris. *As British Honorary Fellows*—Sir Joseph Dalton Hooker, Kew; Dr Spottiswoode, London; Professor Williamson, London; Col. Henry Yule—who were all declared duly elected as Honorary Fellows.

PROCEEDINGS

OF THE

ROYAL SOCIETY OF EDINBURGH.

VOL. XII. 1882–83. No. 114.

Monday, 5th March 1883.

The Right Hon. LORD MONCREIFF, President, in the Chair.

The President read a communication from the Science and Art Department, South Kensington, London, in reference to the International Electrical Exhibition to be held in Vienna.

The following Communications were read:—

1. On the so-called Bicipital Ribs. By Professor William Turner.

In this paper an anatomical peculiarity was described which is occasionally found both in Man and the Cetacea. It is not due to a bifurcation of the shaft of a single rib at its vertebral end into two heads, but to the fusion of what ought to have been the shafts of two distinct ribs into a common body, and it invariably occurs at the apex of the thorax. Although the author had long been familiar with dried specimens from the human body in the Anatomical Museum of the University of Edinburgh, two cases which he now describes were the first that he had seen in the subject itself in the course of nearly thirty years' experience as a teacher of anatomy, and it is remarkable that they should both have occurred within a few months of each other. A third specimen occurred in a skeleton in the possession of one of his pupils, Mr Minas S. P. Aganoor.

A specimen from a large Cetacean was also shown and described. It formed a part of the skeleton of a *Balænoptera*, some of the bones of which were found in 1859, others in 1863, embedded in clay in

Christie's brickfield, in the carse land near the town of Stirling, and about 100 yards from the bed of the River Forth. They were lying in the "blue slink," from 13 to 14 feet below the present surface, and from 3 to 4 feet above the present high-water mark.

The following conclusions were stated :—

1. In both Man and the Cetacea cervical ribs are occasionally developed in connection with the 7th vertebra.

2. In both the cervical ribs may remain free or be fused with the 1st thoracic rib, so as to make it bicipital.

3. In Man a similar bicipital form may be due to fusion of the shafts of the 1st and 2nd thoracic ribs with each other at their vertebral ends, and it is probable that this may also occur in the Cetacea.

4. In either of the forms of fusion specified in 2 and 3, the two limbs, into which the vertebral end is divided, lie in different transverse planes, and the bifurcation is due to the partial fusion of two morphologically distinct rib-elements.

5. The presence of a cervical rib, or the bicipital form of the 1st rib, is only an individual peculiarity, and is not to be regarded as affording any evidence of either specific or generic difference.

The paper will appear *in extenso* in the *Journal of Anatomy and Physiology*, April, 1883.

2. Oscillations and Waves in an Adynamic Gyrostatic System. By Sir William Thomson.

3. On Gyrostatics. By the Same.

4. On the Dynamical Theory of Dispersion. By the Same.

Professor Tait laid upon the table a series of Photographs of Astronomical Instruments made at the new works of the Geneva Society for the Manufacture of Scientific Instruments. These photographs were sent by the Astronomer-Royal for Scotland.

BUSINESS.

The following candidates were balloted for, and declared duly elected Fellows of the Society :—Mr William Evans Hoyle, M.A., M.R.C.S. ; Mr James Duncan Matthews ; Mr James Greig Smith, M.A., M.B. ; Mr John Archibald, M.B., C.M. ; Mr Robert Rowand Anderson ; Mr Andrew Gray.

Monday, 19th March 1883.

Professor DOUGLAS MACLAGAN, M.D., Vice-President, in the Chair.

The following Communications were read :—

1. On the Impossibility of Inverted Images in the Air. By Edward Sang.

It is narrated that a physician, having given cogent reasons to show that there could be no recovery, and somewhat disconcerted by the return of sound health, yet maintained the cogency of his pathological arguments. The present may be a new edition of the same story; however, we shall advance the arguments, and leave it to futurity to tell whether there be any patient at all.

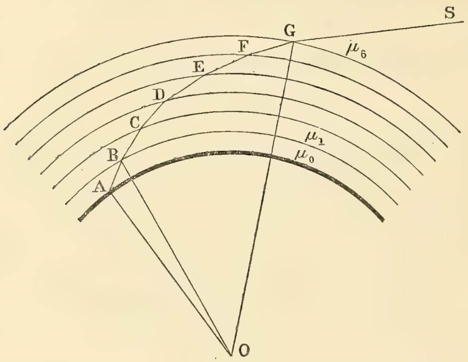
In order that an inverted image of any object be seen in the air, it is, in the first place, requisite that the light from that object, proceeding obliquely upwards, be bent again down to reach the eye of the observer; and, in the second place, that this retroflection occur in a determinate manner, so that the lights proceeding from different parts of the object may arrive in contiguous directions. These effects must be produced by the action of the air. The law according to which transparent media change the direction of light has been well known from direct experiment, and the index of refraction of air has been carefully measured.

In proceeding upwards, the light reaches air of gradually decreasing refractive power, so that the path is curved, the form of the curve depending on the law of diminution of the air's density, and also on the earth's roundness. The manner of the diminution of density is imperfectly known, and hence astronomers encounter great difficulty in investigating the amount of refraction for the stars; that amount, in fact, being computed from empirical formulæ. Yet there are relations among the heights, refractive powers and directions, very easily investigated; and, because of its great simplicity as well as for the sake of those who may not previously have looked at the matter or who may have been frightened by the display of algebraic symbols, I shall here give the analysis.

If the air were composed of concentric layers, each, within itself,

of uniform density, the path of the light would be a series of straight lines, AB, BC . . . GS; refraction taking place at each junction.

If O be the earth's centre, and AB the path of the light in the first layer, the angle OAB, called by astronomers the nadir-distance,



is the incidence of the light upon the surface at A, while OBA measures the incidence of the same light upon the surface at B; and according to the most elementary laws of geometry, we have the proportion

$$\sin OAB : \sin OBA :: OB : OA.$$

If now μ_0, μ_1 be the indices of refraction for the first and second layers, the refraction at B must, according to the well-known law, be such that

$$\sin OBA : \sin OBC :: \mu_1 : \mu_0,$$

so that, on combining the two ratios, we have

$$\sin OAB : \sin OBC :: OB . \mu_1 : OA . \mu_0;$$

which proportion may also be represented by the equality

$$\sin OAB . OA . \mu_0 = \sin OBC . OB . \mu_1 .$$

The analogous equality holds for the path BC, and so along the whole course of the light, wherefore the continued product of the sine of the incidence, the radius vector and the index of refraction, is constant all along; that is to say, the equality

$$\sin OAB . OA . \mu_0 = \sin OGS . OG . \mu_6$$

holds good independently of the variations between the points A and G, and of the thickness or thinness of the supposed layers.

Hence if these three factors be known for any one point in the path, and if two of them be given for another point, the third factor corresponding to that point may be at once computed.

In this part of the theory of atmospheric refraction there is no difficulty; the astronomer's trouble is in discovering the geocentric angle AOG.

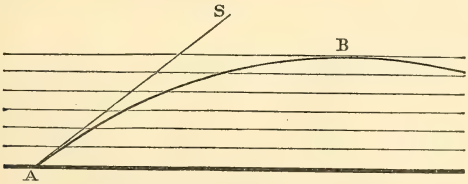
If the earth had been flat, the computations would have been still simpler; the product of the sine of the zenith distance by the index of refraction would have been constant, independently of the height, and the astronomer would have deduced the true from the apparent place of a star by a simple proportion.

M. Biot has given the index of refraction for air at 1.000 294. It varies with the pressure and temperature, and the formula

$$\mu = 1 + \frac{b}{100\,000}$$

in which b stands for the height of the barometer in English inches, is sufficiently near for our purpose, is, perhaps, within the limits of error of the observations.

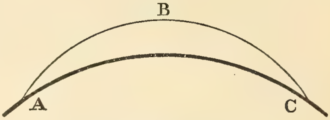
A ray of light rising obliquely from a point on the surface of a flat earth until it arrived at the upper limits of the air would have had the sine of its zenith distance augmented in the ratio of 1.000 000 to 1.000 294; and if the apparent zenith distance at the outset had been 88° 38′, that is, if its angle of elevation had been 1° 22′, whose secant is 1.000 294, the zenith distance at the upper surface of the air would have been 90°. No sun, moon, or star could have been seen at a lower altitude than 1° 22′. All light



reaching the eye from a lower elevation must have come from some terrestrial object after having culminated as at B. The images of terrestrial objects would have been seen constantly in the air, but distorted by the retroflection,—the amount and character of the

distortion depending on the manner of diminution of the air's density.

In the actual case of the round earth, the phenomenon of a reflected image must necessarily lie between the above limit and horizontality.



If a ray of light leave the point C, culminate at B, and reach the eye at A with a zenith distance, which we shall denote by A, the incidence at B must be 90°, and therefore we must have the equality

$$OA \, . \sin A \, . \, 1.000\,294 = OB \, . \, \mu_B \, ,$$

or counting in English miles, and taking the earth's radius at 3960,

$$\sin A \times 3961.167 = OB \times \mu_B \, ;$$

now the smallest possible value of the index of refraction μ_B is unit, hence the maximum value of OB is

$$\sin A \times 3961.167 = OB \, ;$$

wherefore, since the greatest possible value of sin A is also unit, it follows that the utmost limit of OB, under any circumstances whatever, is 3961.167 miles; that is to say, no culmination of light in the atmosphere can take place at a height of more than 1·167 miles, or 6200 feet. But this light must reach the eye horizontally. If the angle A be less than 90°, the radius vector OB must be lessened in proportion to the sine; so that for A = 88° 38′, OB becomes 3960,—that is to say, no inverted image can be seen at an elevation of 1° 22′, unless the atmosphere have only an infinitely small thickness.

We are thus brought quite to home. Our researches do not extend into the regions of the aurora and magnetic arc; they are within the range to which our ordinary barometric measurements are known to apply with very considerable precision.

This result comes from the known index of refraction of air, and from the earth's dimensions, irrespective of all usual or unusual conditions of the air below the limit of culmination; but it requires that at that limit the air should altogether cease.

Let us examine the conditions needed in order that the light become horizontal at a lower level—say at the height of half a mile. In this case the index of refraction at B is obtained from the equality $\sin A \times 3961.167 = 3960.5 \times \mu_B$, or

$$\sin A \times 1.000\,168 = \mu_B,$$

which has possible solutions within two limits—one when $\mu_B = 1.000\,000$, in which case A would be 88° 57′, that is, the elevation would be 1°·03′; the other when A is 90°, giving $\mu_B = 1.000\,168$, which index of refraction would be due to a pressure of 17 inches of mercury. We have no idea of how such a rarefaction of the air at the height of only 2600 feet could be brought about.

To come still nearer home, let us propose an altitude of only one-tenth part of a mile, or 528 feet. We then find that with A = 90°, the index of refraction at the culminating point must be 1.000 269, which belongs to air under a pressure of 27 inches of mercury. This diminution of density cannot be due to the lessened pressure of the air, which, instead of 2·5 inches, would only give ·6, or about the quarter of the required reduction. In lowering the culminating point, we come nearer to the conditions of a flat earth, and therefore to the possibility or probability of a reflected image. Let us then inquire into the conditions when the light is close to the earth along its whole path, and tangent to the surface at C and at A.

If we put h for the height in miles, and A = 90°, the index of refraction is

$$\mu_B = \mu_0 \times \frac{3960}{3960 + h},$$

or developing the fraction into series—

$$\mu_0 - \mu_B = \mu_0 \left\{ \frac{h}{3960} - \frac{h^2}{3960^2} + \&c. \right\}$$

Even at the absolute limit $h = 1·167$, the second and following terms of the series are too small to be of any account in our present inquiry, and thus we may hold that the diminution of the index would need to be at the rate of $\frac{\mu_0}{3260}$ = ·000 2526 for each mile of altitude. The diminution of the barometric pressure corresponding to this would be 25·26 inches of mercury for each mile, or ·00478

for each foot of rise. But that caused by the lessening of the atmospheric pressure is only ·00114, or less than the fourth part of what is needed; and therefore we conclude that no light can be retroflected in the usual condition of the atmosphere.

Inverted images, then, can only be seen when the air is in an unusual condition; there must be unusually light air above. Now, in these, as in all investigations on the subject, the air is assumed to be disposed in horizontal layers, each of uniform density; without such an arrangement no definite refraction can take place, no distinct image, whether distorted or not, can be formed.

The absolute need for smoothness of arrangement may easily be illustrated:—The sun's light is certainly reflected from the surface of the sea; yet we do not see an image of the sun in the water: we see only a confused brightness. When the air is quite still, the sea becomes smooth enough to give an image, which, however, the slightest breath of wind destroys. We cannot use a dish of water as an artificial horizon, we must cover even our trough of mercury with a glass screen to prevent the ripple caused by the wind. Here gravitation tends to produce and to preserve the evenness of the surface. Water is some seven hundred, mercury is ten thousand times heavier than air, and yet the friction of the air produces such disturbance.

Suppose then that we had a liquid as light as, or only a little heavier than air, and that we had poured this liquid into a flat dish. Paying no attention to the density of the wind which may blow upon it, let us think how calm the air would need to be that there may be no ripple on the surface. But let us add to this the consideration of the fact that the almost equality of the two densities deprives gravitation of its power to stratify, and we must admit that the slightest horizontal motion would be destructive of all smoothness.

Imagine a stratum of air of the requisite depth and in its usual state quite level on its upper surface, and let us place upon that a layer of light air of the requisite refractive power, we shall then have inverted images. But our strata are not liquids; they must be pressed upon to keep them from expanding, there must be air above them. If the superior air have its density conformable to the lower stratum so as to be in equilibrium with the general atmosphere beyond, it must be denser than the inserted layer, and the

two would inevitably mix. If, on the other hand, the superior air be conformable to the upper layer its altitude must be greater than that of the general atmosphere which would press in to displace it. In neither case could there be repose.

But the question arises, "how is this layer of lighter air produced?" It cannot be from the sun's warmth in still weather, because then the heating is at the surface of the earth or of the water. The warmed air mixes with the cold above, ascending while the other descends, and giving rise to the too-well-to-the-astronomer-known boiling of the sun's edge.

The only other source of such warm air is in the south, whence the south-west wind brings it to us in gusts and squalls. At the oncoming of the breeze we may see changes in the appearance of distant objects on the horizon; they are displaced, distorted, horizontally, vertically, obliquely, according to the passing whims of Eolus. Seldom more than telescopic, they are as changeable as the squall itself. We can scarcely imagine that the wind should gently lay a warm coverlet over the quiet cold air of the north and leave it there in repose.

But, I shall be told, these images have been seen, your patient is alive and well, Professor Vince saw him from Ramsgate.

I have already shown that Vince's narrative is inconsistent with ordinarily known appearances, and I have pointed out that the same observer, after eight years' further experience as Professor of Astronomy and of Experimental Philosophy at Cambridge, was able to see through a telescope magnifying thirty times, a building fourteen miles away in all the beautiful proportions of near perspective. This feat could only have been performed by one totally ignorant of, or utterly careless of, the simplest laws of geometry and of optics.

Yet I needed not to have gone so far. When a picture is presented to us, we, without requiring an explanation, form an idea of what it means. It may be the picture of a horse, badly drawn, yet still we recognise the limner's meaning, he meant to have drawn a horse. So when I look at Vince's figure, I perceive that he meant to have drawn a sloop; he has succeeded in drawing a sloop such as neither I, nor you, nor any other person ever saw. But I see a great deal more, I recognise in the picture the unmistakable well-known features of an old acquaintance.

The picture is that of a sloop floating on a calm sea with its shadow in the water; the sharpness of the image is considerably overdone, very few persons have seen it so sharp. But the characteristic feature is there; the image and the ship are united at the water-line; it is a well known and understood appearance.

Oh! but Vince saw it up in the air!

When the sea is smooth, the reflection of the sky from the water and the light of the sky itself are so nearly balanced as to be undistinguished, hence the difficulty (sometimes amounting to impossibility) which the seaman has in bringing down the sun to the water-edge. He is unable to tell where the sea ends or the sky begins.

When the breath of a zephyr touches such a sea, it causes a dark space which is foreshortened into a narrow streak. Such streaks are apt to be mistaken for the true horizon, and the sailor-apprentice may find himself wrong in his latitude; but the mate or the captain has been on his guard.

Here, then, is the whole diagnosis of Vince's drawing:—He had seen a sloop floating on a very calm sea, the captain had taken the opportunity to air his canvas, some stray spars or some seaweed had been on the edge of a ripple in-shore, and the Professor's powerful imagination had manufactured wonders out of the vision.

2. On the Thermo-electric Positions of pure Rhodium and Iridium. By Professor Tait.

3. Observations on the Growth of Wood in Deciduous and Evergreen Trees. By the late Sir R. Christison, Bart., and Dr Christison.

4. The Variation of Temperature, with Sun-Spots. By Mr A. Buchan.

Monday, 2nd April 1883.

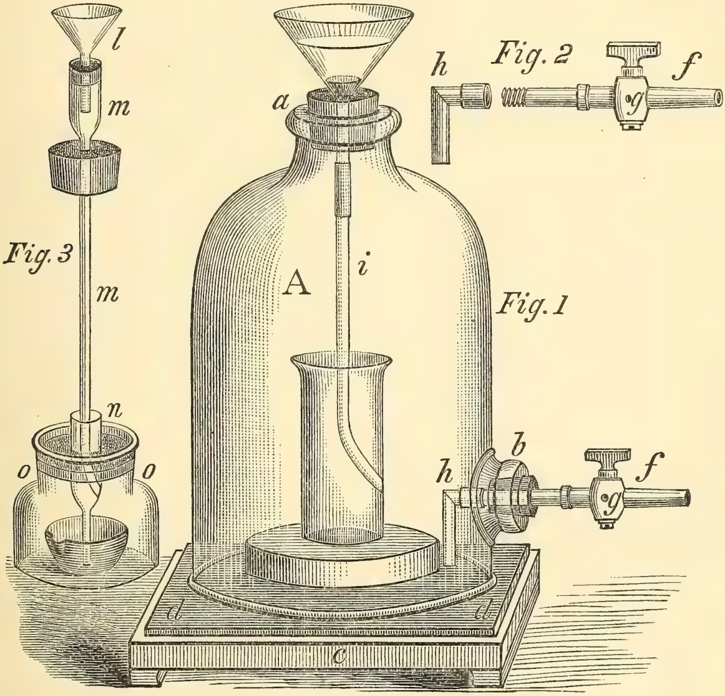
MR JOHN MURRAY in the Chair.

The following Communications were read:—

1. On some Laboratory Arrangements. By Dr John Gibson.

Improved Method of Filtration by Diminished Pressure.

This apparatus will be best understood by a reference to the figures. The bell-jar A (fig. 1) rests, during filtration, on a square block of hard wood *c*, 25 cm. square by 25 mm. thick, over which is laid



a sheet of vulcanised rubber *d* of good quality, and not less than 3 mm. thick. In the centre is a circular disk *e* also of hard wood, 13 cm. in diameter and about 20 mm. thick, which is held in position by four strong brass screws which pass down through the rubber into the square block below. In order to prevent air

leaking through the holes thus made, they are rendered quite air-tight by embedding the screw heads, which are sunk slightly below the surface of *e*, in red lead, and by laying, previous to screwing down, layers of red lead on both sides of the rubber sheet. The red lead should not, however, spread beyond the disk *e* on either side of the rubber sheet, so that the latter lies quite free except where it is held down by the disk. In *b* is fitted a single-bore rubber cork holding the brass tap *f*. This tap is simply an ordinary brass tap converted into a three-way tap by boring a hole *g* through one outer wall and through one wall of the plug, which enables the operator to establish communication between

(1) The bell-jar and pump.
(2) The outer air and both bell-jar and pump.
(3) The outer air and pump, the bell-jar being shut off.
(4) The outer air and bell-jar, the pump being shut off.

After fitting in the cork and tap, the knee-piece *h* (fig. 2) is screwed on. The object of this knee-piece will be explained later on. If the mouth *a* be closed by a rubber stopper, and the tap *f* connected by a rubber tube with a water-pump or other exhausting apparatus as the pressure inside diminishes, the rubber sheet bulges up inside the bell-jar, and pressing against the lower edge closes up any interstices due to irregularity of its own surface, or to imperfect grinding of the glass. A well-made water-pump will give within half an hour a high degree of exhaustion, and this without the use of any lubricant whatever. Where a very high degree of exhaustion is required, the application of a little grease outside round the lower edge of the bell-jar is advisable. The apparatus in this form can therefore be used for drying substances in vacuo, &c. For the purpose of rapid filtration such complete exhaustion is not, as a rule, required, and indeed is often positively detrimental, and defeats the object in view.

All the essential parts of the apparatus have been now described, everything else which is required for filtration being either in ordinary laboratory use, or else can be made with but little time and trouble, and at almost no cost.

When it is desired to collect the filtrate in a beaker or flask, the simplest arrangement is that represented in fig. 1. Fixed in *a* by means of a rubber stopper is an ordinary correct-angled funnel,

fitted with platinum cone and filter in the ordinary way. To the stem of the funnel the glass tube *i*, bent as shown in the figure, and having the lower end ground obliquely, is attached by a short piece of black rubber tubing, the upper end of the tube being pushed up so as to be in actual contact with the stem of the funnel. The bend makes it easy to cause the end of the tube to touch the side of the beaker, which prevents spirting. It will be found convenient to keep several such tubes of different lengths ready made to suit larger and smaller vessels. Before commencing operations it is as well to slightly moisten the rubber sheet *d* with water. This is not by any means absolutely necessary, but causes a quicker gripping of bell-jar and rubber. The tap being in position No. 2, and connected with a water-pump in full action, filtering is commenced by first filling up the filter nearly full with the liquid to be filtered, and then establishing communication between the pump and the bell-jar by turning the tap to position No. 1. During the operation of transferring the precipitate to the filter, it is often necessary to lessen the rate of filtration by diminishing or destroying the difference of pressure outside and inside of the bell-jar. Instead of slipping off the rubber tubing connecting with the pump, this can be far more quickly and easily done by giving the tap a half-turn back to position No. 2, and thus allowing air to rush in both to the pump and to the bell-jar. The use of the knee-piece *h* will be now apparent, for by it the inrush of air is diverted away from the vessel inside, which might otherwise be blown against the side of the bell-jar, and upset or broken. As it is, however, the vessel inside is not at all affected by the inrush of air, however suddenly the tap be opened. In this connection another use of the knee-piece may be pointed out. Several of the otherwise very convenient and inexpensive high pressure water-pumps, now so much used, have a tendency to allow the water to run back under certain conditions, especially when a high degree of exhaustion is attained. Filtering directly into an exhausted flask, such an accident would cause the loss of an analysis, and a valve is therefore usually placed between the pump and the flask. Such a valve is quite unnecessary while using the above apparatus. The running back of the water can be at once stopped without diminishing the pressure inside the bell-jar by giving the tap a quarter turn, so as to admit air to the pump only. Even if water does run back into the bell-jar no harm

is done, and by turning the knee-piece downwards the pump will suck back the water again almost to the last drop.

It is sometimes necessary in quantitative analysis to filter a small quantity of liquid directly into a small weighed platinum basin or crucible. For instance, in filtering the alkaline chlorides from the last traces of magnesia in a silicate analysis, or, to take another example, in the purification of minute quantities of alkaloids.

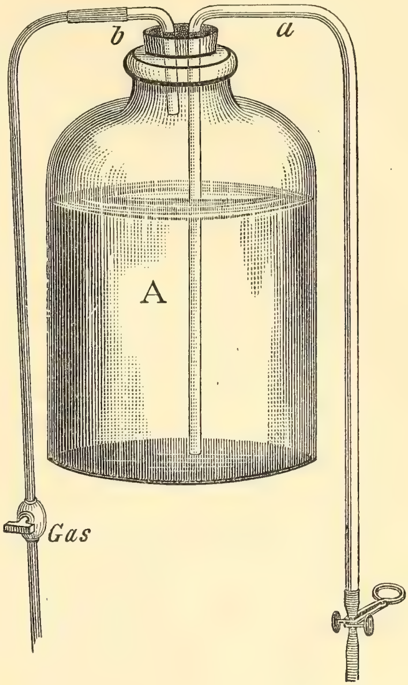
This may be readily done by the arrangement shown in fig. 3. The small funnel *l*, instead of fitting into the large stopper at *a*, fig. 1, is fixed by means of a small cork into the wide end of the stout glass tube *m* (fig. 3).

In order to avoid loss by spirting, the tube does not dip directly into the basin, but into the glass tube *n*. This tube may be made out of a broken pipette, and is supported by a loosely-fitting cork in the small bell-jar *o*, which may be most conveniently made by cutting off the lower half of an ordinary wide-mouthed bottle. When the filtration is over the small funnel *l* and cork should be removed, and the wide part of the tube *m* washed with a very little water, which serves at the same time to wash down the inside of the tube *n*. By this means the amount of wash water is reduced to a minimum. In the estimation of alkaloids the solvent is often chloroform or ether, which dissolve india-rubber, so that in such cases a small ordinary cork should be substituted for the rubber cork in *m*. It may be further pointed out that with this apparatus it is an easy matter to filter liquids containing hydrofluoric acid, which attack glass, by using a platinum funnel and filtering directly into a platinum basin or other platinum vessel.

A Convenient Method for Preserving Sulphuretted Hydrogen Water.

A large bottle A (fig. 4) is fitted with a double-bored cork. In the one hole is the syphon tube *a* leading from the bottom of the bottle to any convenient point lower than the other end of the tube, and closed at this lower end by a short piece of rubber tubing and an ordinary nipper tap. Through the other hole passes the short glass tube *b*, bent at right angles, and attached by means of rubber tubing to a piece of lead piping *c* fitted with a tap, below which tap *c* is soldered on to a pipe connected with the ordinary coal-gas supply.

By this arrangement the sulphuretted hydrogen is preserved from oxidation, and can always be run off perfectly clear. The gas tap should as a rule be kept closed, and need only be opened for an instant when the sulphuretted hydrogen water ceases to flow. It should be well oiled but not greased.



The only objection, if any, that I have been able to discover to this method is that after a time the smell of the sulphuretted hydrogen water becomes somewhat altered in character, apparently owing to the formation of traces of some organic sulphur compound, the nature of which I have not yet been able to examine.

2. On the Thermo-electric Position of pure Cobalt. By Professor Tait.

3. Transmission of Power by Alternate Currents. By Prof. George Forbes.

When a current of electricity is sent through a dynamo machine in the same direction as the current flows when the dynamo is being used as a generator, then the field magnets are polarised in their normal manner, and the magnetism of the armature is such as to cause it to rotate in the opposite direction to that in which it turns when generating a current. The dynamo now acts as a motor. If now the current be sent through the dynamo in the opposite direction, the field magnets are polarised in the opposite manner, *i.e.*, a north pole is found where a south pole was before. The same is true of the magnetism of the armature. Hence, in this case the

poles, both of the field magnets and of the armature, are simply interchanged, and the rotation is again in the direction opposite to that in which it runs as a generator.* It thus appears that when a current of electricity is passed through an ordinary dynamo machine, the armature always rotates in one direction, whatever be the direction of the current. If, however, the field magnets or the armature be furnished with a current fixed in direction, the rotation of the armature may be reversed by reversing the direction of the current in the other part of the machine.

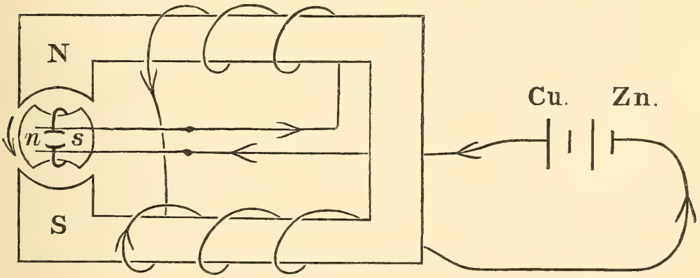
Such being the case, it would seem likely that if currents of varying direction be passed through a dynamo they would cause continuous rotation in one direction. I sent the current from a Siemens alternate-current machine through a small Griscom motor, which has a Siemens armature with only two reversals of the commutator in each revolution. Under these conditions the motor did not move at all, in whatever position of the armature it was tried. The reason of this is that the reversals of direction of the current are too rapid to allow of the complete reversal of the magnetism, both in the field magnets and the armature. This has been noticed before, and consequently it has been supposed that motive power cannot be transmitted by an alternate-current machine.

When the apparatus was in the same condition as described above, I gave a rapid rotation to the motor by hand, and after it had reached a certain speed the alternate-current maintained the rotation at a steady and uniform speed. I put some pressure on the spindle of the motor. It rotated at the same speed. I increased this pressure. The speed did not vary. But on continuing this action I arrived at a point where suddenly the driving action ceased, and if the motor continued to turn it was almost entirely owing to its own momentum; but not entirely so, for on removing the pressure entirely, while the motor was still running slowly, the speed rapidly increased until it reached the previous uniform rate. The sudden diminution of driving power, when a certain amount of friction was applied, was very remarkable.

What is the explanation of this action? The fact that a uniform speed of rotation is maintained, and never exceeded, points to a synchronism between the revolutions of the armature and the

* I only speak of the magnetic actions for simplicity of expression. The electric actions are in the same direction as the magnetic.

reversals of the alternate-current as being the true cause. In the Griscom motor the current comes from the source of electricity to one arm of the commutator attached to the Siemens armature, whence it is carried by the coil of wire surrounding the armature to the other arm of the commutator. The current leaving this arm of the commutator goes round the arms of the field magnets and magnetises the poles. Suppose now that by the rotation of the armature the reversal of the commutator takes place at the same time as the reversal of the current, then the two simultaneous reversals will cause the current always to circulate in the same direction through the coils, and one part of the armature will always be north and the other always south. But the current exciting the field magnets is constantly being reversed, although so rapidly as to allow of only a very slight magnetisation. Thus suppose that when the left side of the armature is north, the upper field magnet is north, it follows that when this one is south the other is south also, so that there is always repulsion and consequent rotation in a direction opposite to the hands of a watch.



It will be seen now that when we tried to start the motor with alternate currents, we had only the feeble interaction of the two pieces of iron extremely feebly magnetised; but when we have synchronous rotation, we have the more powerful interaction of a continuously excited and strong magnet (the armature), and the still feeble action of reversed magnetism of the field magnets. It is easy to see that if the armature tends to go too quickly or too slowly, the attractions between the movable and fixed parts will tend to check this irregularity. This accounts for the maintenance of the synchronism. It is also clear that if the speed be too much diminished

by causing the armature to do work, the magnetic attraction will not act, and this amount of work will speedily stop the rotation of the armature. It is also clear that if the armature be *not* revolving in synchronism, and be doing no appreciable work, the magnetic attractions will always be tending to bring it more nearly to synchronism. These conclusions are all in accordance with what I observed.

This is all that I have done as yet in an experimental way on the transmission of power by alternate currents. It is easy to follow out the results which must follow when a machine with a Pacinotti collector (or commutator) is used, or when a magneto-electric motor is employed. But I will not enter on this subject until I have experimental data to support these conclusions.

I have considered these results, small as they may appear, to be worthy of the attention of this Society, because of the great value which I attach to the transmission of perfect synchronism. It is well known that in the construction of motors a great deal of ingenuity has been expended in endeavouring to obtain a steady speed, while the motor is doing a variable quantity of work. This difficulty is completely overcome by the use of alternate currents. It is true that the efficiency of my motor was small, owing to the feeble magnetism of the field magnets; but perhaps this can be overcome. I have said that the motor I used was one of the well-known Griscom motors, and the current I used was 1½ ampères, measured by a Siemens dynamometer. From an exceedingly rough estimate of the pressure on the pulley which was required to stop the motor, and the surface velocity of the pulley, I believe that I obtained about 200 ft. lbs. per minute.

But it is not the regularity of speed of motors which strikes me as important so much as the power to transmit absolute synchronism to a distance. It is, of course, well known that the main feature of many telegraph systems is "synchronous action." This is the case with the Hughes printing telegraph, so unfortunately neglected in this alone of all-important European countries. So it is with the Baudot and other modifications of the Hughes, and still more so is it the case with the autograph systems of Caselli, D'Arlingcourt, and others.

4. On the Homology of the Neural Gland in the Tunicata with the Hypophysis Cerebri. By W. A. Herdman, D.Sc., F.L.S., Professor of Natural History in University College, Liverpool.

(*Abstract.*)

In an ordinary simple Ascidian, where both the branchial and atrial apertures are at or near the anterior extremity of the body, the region lying between them—the interoscular area of Lacaze-Duthiers—is small in extent, and contains three important structures, the nerve ganglion, the neural gland, and the dorsal tubercle, lying close together. The ganglion in such a case is elongated dorso-ventrally, and gives off nerves at its two extremities, one set ventrally and anteriorly towards the branchial aperture, and the other set dorsally and posteriorly towards the atrial.

In those species, however, in which the atrial aperture is near or at the posterior end of the body, the interoscular area is large, and forms the dorsal edge of the body. The nerve ganglion may remain anterior in position, or it may be placed far back so as to be nearer to the atrial. In this case, the nerves given off from the extremities of the ganglion run, the one set anteriorly and the other posteriorly.

Wherever the ganglion may be, the neural gland is always found in close relation to it, either upon its posterior or ventral surface, according to the direction in which the long axis of the ganglion is placed. This neural gland consists of a mass of more or less ramified cæcal tubules imbedded in connective tissue, and all springing from a central space or wider tube which underlies the ganglion. The presence of this organ was first distinctly pointed out by Albany Hancock in 1868,* but this able investigator does not seem to have assigned any function to it.

The mysterious dorsal or "olfactory" tubercle was first described by Savigny in 1816, under the name of "tubercule anterieur." Since then it has been discussed by almost all who have worked at the Tunicata; it has received many names, but has usually been regarded as some sort of olfactory organ. It is invariably placed at the anterior end of the branchial sac, posterior to the circle of tentacles, and usually in a

* "On the Anatomy and Physiology of the Tunicata," *Jour. Linn. Soc. Zool.*, vol. ix. p. 335.

distinct, more or less triangular peritubercular area, which is a diverticulum of the prebranchial zone, and is formed by the dorsal ends of the peripharyngeal band bending posteriorly to meet the anterior extremity of the dorsal lamina.

The dorsal tubercle is, in the simplest form known, a funnel-shaped depression having its wider, circular, anterior end opening freely into the branchial siphon (the tube leading from the branchial aperture to the branchial sac), and separated off from the prebranchial zone by a raised edge or lip. The opposite narrower end is continued into a fine canal running dorsally or posteriorly in the direction of the nerve ganglion. This simple condition is found in *Molgula pedunculata;* in *Eugyra kerguelenensis*, the aperture is still wide, although its edge is square in place of being circular.

In other simple and compound Ascidians, the anterior half of the edge has been apparently pushed backwards so as to become invaginated and closely applied to the posterior half, thus reducing the circular aperture to a crescentic or semicircular slit. This condition is found in *Corella parallelogramma.* In most other forms, more or less complication is produced by the ends of the slit, or "horns" as they may be called, being prolonged often to a very great extent, and coiled in various directions, sometimes producing beautifully regular and closely placed spirals, as in *Molgula gigantea.* The patterns produced by this curving of the horns are very numerous, and often complicated; but their value in classification is slight, since they differ sometimes to a considerable extent in different individuals of the same species, and on the other hand, are sometimes very similar in members of different genera or even families.

Some few forms are known in which, in place of being a single curved or spiral organ, it is formed of several distinct irregularly-shaped apertures, as in *Cynthia irregularis;* this has evidently been formed by the lips of the primitive simple dorsal tubercle having become so folded as to divide the single aperture into several. Lastly, there are cases in which the organ is even more complicated, as in *Boltenia pachydermatina*, so that it becomes very difficult to trace its derivation from a simple circular opening.

This variously shaped organ is histologically merely a depression in the connective tissue of the mantle, lined by epithelium continuous with the squamous epithelium covering the prebranchial zone. These cells are modified upon the edges of the slit into first

cubical, and then columnar ciliated cells. The cilia project into the cavity of the organ.

Since the time of Savigny, the dorsal tubercle has been almost universally regarded as a sense organ of some kind—probably olfactory or gustatory, or in some way capable, as Hancock * suggested, of "testing the quality of the inhaled water." The reasons for this view have been—

1. The position of the organ at the entrance of the branchial sac, where a sense organ would be of great apparent value.

2. Its structure—a ciliated depression covered in part by columnar cells, some of which closely resemble sense cells.

3. Its intimate relation with the ganglion, and the presence of a nerve arising from the anterior end of the ganglion, running towards the branchial aperture, close past the dorsal side of the tubercle, and presumably supplying it with nerves.

In 1876, Ussow † showed that the neural gland lying below the ganglion was continued into a delicate duct, lined by cubical epithelium, which ran forwards and opened into the tubular posterior end of the funnel-like depression forming the dorsal tubercle, so that the variously-shaped slit of the tubercle was thus shown to be merely the aperture of the duct from the neural gland. Long previous to this, in 1861, Keferstein and Ehlers ‡ had shown that the funnel-shaped cavity forming the dorsal tubercle in *Doliolum denticulatum* was continued backwards as a delicate duct to the base of the ganglion, but they regarded this duct and its anterior expansion as a prolongation from the ganglion itself.

In 1881, Ch. Julin § confirmed Ussow's discovery, and described minutely the condition of the gland, the duct, and the tubercle in several species of simple Ascidians. He also declared that there was no connection between the nerve running from the ganglion to the branchial aperture and the tubercle, and that consequently the latter could not be a sense organ, and was nothing more than the opening of the duct. In a second paper published shortly afterwards, Julin || described the condition of these organs in two

* *Loc. cit.* p. 335.
† *Proc. Imp. Soc. Nat. Hist.*, *&c.*, *Moscow*, vol. xviii. fasc. ii. (in Russian).
‡ *Zoologische Beiträge*, iii., "Ueber die Anatomie und Entwicklung von Doliolum," p. 61, Leipzig.
§ *Archives de Biologie*, vol. ii. p. 59.
|| *Archives de Biologie*, vol. ii. p. 211.

additional species, and enunciated the theory suggested to him by E. van Beneden, that the neural gland was renal in function, and was the homologue of the hypophysis cerebri of the vertebrate brain. In favour of this homology may be considered—

1. The position of the gland upon the ventral surface of the nerve centre and above the pharynx.

2. Its glandular nature.

3. Its connection with the anterior end of the pharynx by a duct—Balfour, Kölliker, and others having shown that the hypophysis or pituitary gland in higher vertebrates arises as a dorsal diverticulum from the stomodæum, but afterwards loses this connection.

From my own observations on a number of different forms of the Tunicata, I can confirm Ussow and Julin's statements as to the presence of a duct from the neural gland and its connection with the slit of the dorsal tubercle, and, like Julin, I am unable to find any nerve supplying the supposed sense organ. I have, however, in several cases seen certain of the epithelial cells covering the edges of the slit which had a striking resemblance to sense cells, such as those in the ectoderm of *Actiniæ.* This observation taken along with Julin's descriptions, and especially with the condition of affairs in some specimens of *Ascidia mammillata* which I have recently examined, has suggested to me that possibly the dorsal tubercle may be *both* the aperture of a gland corresponding to the hypophysis cerebri, and also a sense organ, probably of an olfactory or gustatory nature.

Ascidia mammillata is one of the forms discussed by Julin in his second paper. It is a large species, with the branchial and atrial apertures rather far apart, and the ganglion at a considerable distance from the anterior end of the body, the interoscular area being of large extent. Julin found that the neural gland in this species did not form the usual compact mass, but was in a somewhat rudimentary condition, and that besides having the usual duct running anteriorly to communicate with the pharynx by the dorsal tubercle, it had also a number of short funnel-shaped apertures into the peribranchial or atrial cavity enclosed by the mantle; so that in this species the products of the neural gland might be excreted either into the branchial sac by the main duct and dorsal tubercle, or into the dorsal part of the peribranchial cavity by the lateral shorter ducts. This peribranchial cavity communicates directly with the exterior by means of the atrial aperture, and is the cloacal cavity

into which the rectum and the genital ducts open. Its lining membrane is derived from the epiblast, being formed in the embryo by a pair of lateral involutions which afterwards fuse dorsally.

In two specimens of *Ascidia mammillata* which I had an opportunity of examining recently, I found the neural gland in precisely the condition described by Julin, but its duct had no aperture into the pharynx, the dorsal tubercle being entirely absent. The small funnel-shaped apertures into the peribranchial cavity were numerous and well developed, so that in the case of these individuals the neural gland was connected with the cloacal part of the peribranchial cavity only, exactly the arrangement to be expected if the gland had a renal function. Admitting that that is so, and that the neural gland is the homologue of the hypophysis, it seems possible to me that this, or something like this, may have been the condition of affairs in the primitive Chordata previous to the point of divergence of the Urochorda.* There may have been a renal gland placed ventrally to the nervous system—not necessarily at the anterior end only,—and opening on the surface of the body † by one or more laterally placed apertures—this gland being represented in the Tunicata by the neural gland, and in the Vertebrata by the glandular portion of the pituitary body.

As to the dorsal tubercle, whether it has now any sensory function is doubtful, on account of the apparent absence of nerve-supply; but I consider that it must have been a sense organ formerly—possibly placed at first on the surface of the body close to the mouth (the branchial aperture), since the anterior part of the pharynx develops from the epiblast as a stomodæum,—and I would suggest that the connection of the tubercle with the duct of the neural gland may be an afterchange, caused possibly by the enlargement of the pharynx into a branchial sac, and the development of the peribranchial chamber. It may readily be imagined how, as the result of the formation of these cavities, the dorsal tubercle would be brought

* I have adopted Balfour's classification (*Comparative Embryology*, vol. ii. 1881) as follows:—

CHORDATA.

1. Urochorda (Tunicata).
2. Cephalochorda (*Amphioxus*).
3. Vertebrata.

† The lining of the peribranchial cavity into which the ducts open in *Ascidia mammillata* has been already shown to be continuous with the ectoderm on the surface of the body.

into closer relation with the neural gland, and one or more of the funnel-shaped ducts of the gland might, after having been carried in from the surface by the formation of the lateral atrial involutions, come to open into the ciliated depression of the tubercle in place of into the peribranchial cavity. The condition thus produced would be very much what Julin has described as existing in his specimens of *Ascidia mammillata.* If now for some reason the original openings into the peribranchial cavity became suppressed, leaving merely the secondary opening into the pharynx by means of the dorsal tubercle, we would arrive at the condition found in all ordinary Ascidians. It is not easy to see what the cause of the change could be, as there is no apparent advantage to be derived from it; probably, however, there is no disadvantage since there is abundant communication between the branchial sac and the peribranchial cavity through the stigmata or slits in the wall of the former.

This suggestion as to the origin of the present structure and relations of the neural gland and neighbouring organs, in most Tunicata, implies that the pituitary body in the Vertebrata, which has lost its connection with the exterior, and probably also its function, has a similar history. In this view I am encouraged by some remarks by Balfour * from which it is clear that he considered the pituitary body, judging from its development, to have been originally a sense organ, opening into the mouth, and possibly corresponding to the Ascidian dorsal tubercle. He has also suggested † as an alternative the possibility that the neural gland in the Tunicata may be the homologue of the vertebrate pituitary body. This is of course the theory supported by van Beneden and Julin, and is open to the objection that it does not account for the remarkable structure of the dorsal tubercle. The view I hold combines both of those suggested by Balfour and Julin, by considering the pituitary body as the homologue of the neural gland, and as being therefore the rudiment of a primitive neural organ ‡ which opened in the early Chordata by lateral ducts upon the side wall of the body; while the connection of the pituitary body with the stomodæum,

* *A Treatise on Comparative Embryology*, vol. ii. p. 359, London, 1881.

† *Loc. cit.*, p. 360.

‡ Not the pronephros, since that is found along with the pituitary body in many Vertebrates, but possibly more ancestral. Might it not be the homologue of the provisional trochosphere excretory organs described by Hatschek and others in *Polygordius* and some Mollusca?

in embryo vertebrates, is regarded as being not its original and proper duct, but a secondary connection which has been formed with a lost sense organ, placed at or in front of the anterior end of the pharynx, and homologous with the dorsal tubercle in the Tunicata.

In conclusion, Ussow and Julin have conclusively shown that the dorsal tubercle is not *merely* a sense organ. The complex structure which the tubercle usually presents seems to indicate that it is not *merely* the aperture of a duct. Whether, as I suggest, it may be a sense organ into which the duct has come to open can scarcely be determined on the evidence at present in our hands. The lines of investigation which may be reasonably expected to throw additional light upon the matter are—(1) The exact course of development of the neural gland and the dorsal tubercle, and further information as to the pituitary body; and (2) The examination of the condition of the gland and its ducts throughout the Tunicata, and especially in a large number of specimens of *Ascidia mammillata*, a species in which these organs appear to be in a variable and highly interesting condition.

5. On the Quaternion Expression of the *Finite* Displacements of a System of Points of which the Mutual Distances remain Invariable. By Gustave Plarr, Docteur ès-Sciences. Communicated by Professor Tait.

When we try to define, from a purely geometrical point of view, the *rigidity* of a system of points, we are inclined to consider the invariability of the mutual distances of the points a sufficient definition. But when we take this definition as a starting point, in the problem of expressing the *finite* displacements of the system, we soon discover that the invariability of the distances is not sufficient for insuring the invariability of the relative positions of the points.

In this paper we have, with the help of the quaternion-method, transformed the fundamental condition of the problem into an equation which presents two separate factors. One of the factors solves the problem by representing the displacements as a *screw-rotation* of the system. The other factor gives the geometrical *perversion* of the figure which the system possessed before the displacement of its points.

From the expressions of the two kinds of displacements, we are

enabled to deduce the supplementary condition by which the rigidity of a geometrical system shall be established in all its completeness.

Both these expressions are reducible to the same definite form, each expression yielding properties which correspond each to the other in the two kinds of displacement. To the *line* representing the axis of rotation in the screw-rotation corresponds the *plane* representing the plane of symmetry in the perversion; to the translation in the first, parallel to the definite axis of rotation, corresponds a translation in the second, parallel to the definite plane of symmetry.

With the expressions combined of the two kinds of displacement we shall be able to establish a general demonstration of the proposition according to which two given successive perversions are equivalent to a determinate screw-rotation.

§ 1.

Let us consider first the displacements of two points A and B, supposing that they displace themselves to A′ and B′ respectively.

Assuming an arbitrary origin O_1 for the vectors of these points, we put

$$O_1A = \alpha, \qquad O_1B = \beta,$$
$$O_1A' = \alpha', \qquad O_1B' = \beta'.$$

By our hypothesis we must have

$$(1) \qquad \begin{cases} T\alpha' = T\alpha, \\ T\beta' = T\beta, \\ T(\beta' - \alpha') = T(\beta - \alpha). \end{cases}$$

We transform the third of these equations, by the help of the two first, into

$$(2) \qquad S\alpha'\beta' - S\alpha\beta = 0.$$

The most general solution of the two first equations may receive the form

$$(3) \qquad \begin{cases} \alpha' = p\alpha p^{-1}, \\ \beta' = q\beta q^{-1}, \end{cases}$$

where p and q may be any versors whatever.

By these expressions the first member of (2) becomes

$$Sp\alpha p^{-1}q\beta q^{-1} - S\alpha\beta.$$

Let us call Z this expression, so that

$$Z = 0$$

will represent the equation (2).

We represent $q^{-1}p$ by a single letter r, so that

$$q^{-1}p = r\,,$$

giving

$$p^{-1}q = r^{-1}\,.$$

Thus we get

$$Z = S\beta(r\alpha r^{-1} - \alpha)\,.$$

Having generally

$$(5) \qquad r\alpha r^{-1} - \alpha = r(\alpha r^{-1} - r^{-1}\alpha) = 2rV\,.\,(Vr\ \ \alpha)\,,$$

we get

$$Z = 2S\,.\,[\beta\,.\,rV(Vr\,.\,\alpha)]\,.$$

Let ζ be the unit vector of Vr, and let us introduce the factor

$$\zeta^2 = -1$$

under the sign S. Then we get

$$Z = -2S\,.\,[\zeta\,.\,\zeta\beta\,.\,r\,.\,V(Vr\alpha)]\,.$$

Of course, we see at a glance that Z will vanish when we assume

$$TVr = 0\,,$$

in which case we get $r = \pm 1$, and consequently $\pm q = p$: this will be the first solution spoken of. But we will continue to examine the expression of Z independently of the vanishing of Vr.

Decomposing $\zeta\beta$ into its scalar and its vector, we notice that the term in Z depending on $S\zeta\beta$ will vanish, because the factor of $S\zeta\beta$ will have a vector under the sign S. We have therefore

$$Z = -2(TVr)S[\zeta V\zeta\beta\,.\,r\,.\,V\zeta\alpha]\,,$$

or replacing r by $q^{-1}p$, and grouping the factors, we get

$$(6) \qquad Z = -2(TVq^{-}p)S[\zeta(V\zeta\beta\,.\,q^{-1})(pV\zeta\alpha)].$$

Thus far we could advance without making any particular hypothesis about the versors p and q. Now we see that if both had the same axis, that common axis would be identical with ζ, and we could at once deduce some further transformation.

Let us examine how far the generality of the solution of $Z = 0$ will be restricted if we introduce the hypothesis that p and q be co-axial, namely, $UVp = UVq$?

Considering this incidental question from a purely analytical point of view, we observe that the six elements comprised in α' and β' are by the two first conditions (1) reduced to four independent elements, α and β being given. By (3) we introduce six elements

contained in p and q taken together, and, if we introduce the condition

$$\text{(7)} \qquad UVp = UVq = \zeta,$$

we reduce to four the number of the independent elements contained in p and q. By this means we do not reduce the number of the independent elements on which α' and β' depend.

Considering the question in its geometrical aspect, we represent the finite displacements by $d\alpha$ and $d\beta$,* putting

$$\text{(8)} \qquad \alpha' = \alpha = d\alpha\,, \quad \beta' = \beta = d\beta\,,$$

and applying (5) to the expressions (3), we get

$$\text{(9)} \qquad d\alpha = 2pV(p\,.\,\alpha)\,, \quad d\beta = 2qV(Vq\,.\,\beta)\,.$$

Hence

$$\text{(10)} \qquad S\,.\,d\alpha Vp = 0\,, \quad S.\,\delta\beta Vq = 0\,.$$

The directions of Vp and Vq are thus limited to planes respectively perpendicular to $d\alpha$ and to $d\beta$, these planes passing through the origin O_1 of α and β. Moreover these planes contain a definite point each. Namely, if we put (1) under the form

$$(\alpha + d\alpha)^2 - \alpha^2 = 0,$$

we deduce

$$S(\alpha + \tfrac{1}{2}d\alpha)d\alpha = 0\,;$$

likewise we get

$$S(\beta + \tfrac{1}{2}d\beta)d\beta = 0\,.$$

If then α and β, $d\alpha$ and $d\beta$ be given, the axis of p and q may still remain of an indeterminate position each in its plane, perpendicular to $d\alpha$, and containing $\alpha + \frac{1}{2}d\alpha$, or perpendicular to $d\beta$, and containing the point $\beta + \frac{1}{2}d\beta$.

But these two planes generally intersect each other, and if ζ represents the unit-vector in the direction of the line of intersection, we may take this direction for those of Vp and Vq in common without affecting the values of $d\alpha$ and $d\beta$.

We define therefore the expressions of p, q by

$$\text{(11)} \qquad \begin{cases} p = \cos u + \zeta \sin u\,, \\ q = \cos v + \zeta \sin v\,, \end{cases}$$

and we determine the angles u and v by the relations (9); inversely if we give ourselves ζ, u, v as data, the expressions (9) will represent any values of $d\alpha$ and $d\beta$ compatible with the two first conditions (1).

* The characteristic d representing finite differences throughout this paper.

Should $d\alpha$ and $d\beta$ require to be parallel, then we would, *à fortiori*, be entitled to give to $\mathrm{V}p$ and to $\mathrm{V}q$ the same direction, considering that both would be comprised in one and the same plane, and the relations (9) would again determine u and v.

Let us now introduce the expressions (11) into Z, remembering that we have now by (9)

$$(12) \qquad d\alpha = 2p\mathrm{V}\zeta\alpha \,.\, \sin u, \quad d\beta = 2q\mathrm{V}\zeta\beta \sin v \,.$$

Moreover, as

$$\mathrm{S} \,.\, q\mathrm{V}\zeta\beta = 0 \,,$$

we may write

$$\mathrm{V}\zeta\beta \,.\, q^{-1} = q\mathrm{V}\zeta\beta \,.$$

We have now by (12)

$$\mathrm{Z} = \frac{\mathrm{TV}(q^{-1}p)}{2 \sin u \sin v} \mathrm{S} \,.\, \zeta d\alpha d\beta \,.$$

The relations (10) become

$$(13) \qquad \mathrm{S}\zeta d\alpha = 0 \,, \quad \mathrm{S}\zeta d\beta = 0 \,.$$

This gives

$$\zeta = \pm \mathrm{UV} \,.\, d\alpha d\beta$$

$$\mathrm{S}\zeta d\alpha d\beta = \mp \mathrm{TV}.d\alpha d\beta \,.$$

The equation $\mathrm{Z} = 0$ becomes then finally

$$\frac{\mathrm{T.V}(q^{-1}p)}{2 \sin u \sin v} \mathrm{T.V}(d\alpha d\beta) = 0 \,.$$

We have therefore two solutions for the equation (2),

I. either $\qquad \mathrm{T.V}(q^{-1}p) = 0$, namely $\pm q = p$;

II. or $\qquad \mathrm{TV}(d\alpha d\beta) = 0$,

namely, $d\alpha$ and $d\beta$ to be parallel to one another.

We omit such particular cases for which both conditions are satisfied at the same time.

§ 2.

For the discussion of these two solutions we will refer to a fixed origin O, the position of the points which are invariably linked to the system. Let ρ_1, ρ_2, &c., ρ, designate the vectors of these points before their displacements, and let ρ'_1, ρ'_2, &c., ρ' be the vectors of respectively the same points after their finite displace-

ment. For the sake of conciseness, we may designate the points themselves by their vectors. We will also assume that the vectors ρ_1, ρ_2, &c., be given: the vectors ρ'_1, ρ'_2, &c., ρ' will be deduced from them according to the one or the other of the two solutions in question.

Let us consider the groups of three points, ρ_1, ρ_2, ρ, where ρ is to represent (successively) any point of the system, save ρ_1 and ρ_2. We put

$$\rho_2 - \rho_1 = \alpha .$$

And we liken $\rho - \rho_1$ with β, putting

$$\rho - \rho_1 = \beta .$$

The origin of α and β will be at the extremity of ρ_1, say in O_1.

Introducing, for any index, the notation

$$\rho' = \rho + d\rho ,$$

we shall have now

$$d\alpha = d\rho_2 - d\rho_1 ,$$
$$d\beta = d\rho - d\rho_1 .$$

We assume $d\rho_1$ to be given, and then the object of each of the two solutions will be the determination of $d\rho_2$, $d\rho_3$, &c. $d\rho$.

The first solution,

$$\mathrm{TV}(q^{-1}p) = 0 ,$$

gives $q^{-1}p = \pm 1$, or $q = \pm p$. But the double sign disappears in the operator $q\ (\quad)q^{-1}$, which becomes $p\ (\quad)\,p^{-1}$. We have therefore the same operator for all the displacements. Thus we get

$$(14) \qquad \rho'_2 - \rho'_1 = p(\rho_2 - \rho_1)p^{-1},$$

$$(15) \qquad \rho' - \rho'_1 = p(\rho - \rho_1)p^{-1}.$$

Writing (15) for $\rho = \rho_3$, we have

$$(16) \qquad \rho'_3 - \rho'_1 = p(\rho_3 - \rho_1)p^{-1}.$$

The relations (16) and (14) establish the invariability of the triangle, which has its summity in ρ_1, ρ_2, ρ_3, before the displacement, and, in ρ'_1, ρ'_2, ρ'_3 after the displacement of the system.

Looking on this triangle as a basis in reference to which the position of any other point of the system may be defined, we get by (15), and by subtracting successively (14) and (16) from (15),

$$(17)\qquad \begin{cases} \rho' - \rho'_1 = p(\rho - \rho_1)p^{-1}, \\ \rho' - \rho'_2 = p(\rho - \rho_2)p^{-1}, \\ \rho' - \rho'_3 = p(\rho - \rho_3)p^{-1}, \end{cases}$$

and by these relations the distances of ρ' from the summits ρ'_1, ρ'_2, ρ'_3 of the displaced triangle are equal to the corresponding distances of ρ from the summits ρ_1, ρ_2, ρ_3 before the displacement of the system.

If we take the scalar of the product member to member, we get, owing to $p^{-1}p = 1$:

$$(18)\qquad S(\rho' - \rho'_1)(\rho' - \rho'_2)(\rho' - \rho'_3) = +S(\rho - \rho_1)(\rho - \rho_2)(\rho - \rho_3).$$

We shall refer again to this result when we have the corresponding result calculated by the second solution.

By the second solution, we must satisfy the condition

$$TV(d\rho_2 - d\rho_1)(d\rho - d\rho_1) = 0,$$

and as ρ represents any point of the system, it follows that all the relative displacements $d\rho - d\rho_1$ must be parallel to one another.

Let us designate by η the unit-vector in the direction of these displacements. We shall then have, when $\beta = \rho - \rho_1$,

$$\begin{aligned} d\beta &= \eta g \\ \beta' &= \beta + \eta g \\ \beta'^2 &= \beta^2 + 2gS\eta\beta - g^2. \end{aligned}$$

Applying (1), namely $T\beta' = T\beta$, we get

$$O = g(2S\eta\beta - g).$$

Omitting $g = 0$, which corresponds to no displacement at all, we get

$$d\beta = 2\eta S\eta\beta,$$

and

$$(19)\qquad \beta' = \beta + 2\eta S\eta\beta;$$

or with the signification of β :

$$\rho' - \rho'_1 = \rho - \rho_1 + 2\eta S\eta(\rho - \rho_1).$$

From this, making successively $\rho = \rho_2$, $\rho = \rho_3$, and proceeding as in the case of the first solution, we establish, first the invariability of the triangle of which the summits are in ρ_1, ρ_2, ρ_3, before the displacement, and in ρ'_1, ρ'_2, ρ'_3 after the displacement. Secondly, we establish the three relations following:

$$(20)\qquad \begin{cases} \rho' - \rho'_1 = \rho - \rho_1 + 2\eta S\eta(\rho - \rho_1), \\ \rho' - \rho'_2 = \rho - \rho_2 + 2\eta S\eta(\rho - \rho_2), \\ \rho' - \rho'_3 = \rho - \rho_3 + 2\eta S\eta(\rho - \rho_3), \end{cases}$$

by which the distances of ρ' from ρ'_1, ρ'_2, ρ'_3 are respectively the same as those of ρ from ρ_1, ρ_2, ρ_3.

We now take the scalar of the product member to member. This gives for the second member,

$$S.(\rho - \rho_1)(\rho - \rho_2)(\rho - \rho_3)$$
$$+ 2S.\eta\Sigma V(\rho - \rho_1)(\rho - \rho_2)\, S\eta(\rho - \rho_3),$$

where Σ represents the summing of the three terms obtained by the circular permutation of the indices. But this sum represents the vector

$$\eta S.(\rho - \rho_1)(\rho - \rho_2)(\rho - \rho_3),$$

and, treated by $2S\eta$, we get a term which reduces itself so as to give:

$$(21)\qquad S.(\rho' - \rho'_1)(\rho' - \rho'_2)(\rho' - \rho'_3) = -S.(\rho - \rho_1)(\rho - \rho_2)(\rho - \rho_3).$$

If we compare the sign in the second member of this result (21) with the sign in the corresponding result (18), we see at a glance that the displacements of the second solution produce a state of things which is incompatible with the conditions which constitute a physically rigid system, and that therefore the relation (18) alone characterises the systems which possess the complete rigidity from a geometrical point of view.

As we have at our disposition *two* different expressions of the displacements according to the second solution, namely, the expressions (3) (with the values (11) of p and q) and the general expression (19), we will investigate into the properties of the second solution in using both expressions. But we will discuss first the properties of the first solution, and then, taking up the second, we will at the same time be able to show the correspondence (from a formal point of view) of the properties of both solutions.

§ 3.

By the first solution we have the expression (17), of which we write again the first

$$(22)\qquad \rho' - \rho'_1 = p(\rho - \rho_1)p^{-1},$$

and which applies the same operator $p(\quad)p^{-1}$ to any point of the system. Let us look upon p as a datum. Moreover as

$$\rho'_1 = \rho_1 + d\rho_1 ,$$
$$\rho' = \rho + d\rho ,$$

we assume also that the displacement $d\rho_1$ of the extremity of ρ_1 be *given,* so that the expression (22) will serve to the determination of the displacement $d\rho$ of the extremity of ρ, which may be any point of the system, or also, in this case any point invariably connected with the points of the system of given points.

Let us determine the point, or locus of points, of which the displacement is parallel to the axis ζ of p. If ρ_0 designates such a point we define it by putting

(23) $$\mathrm{V}.\zeta d\rho_0 = 0 ,$$

or

(23 *bis*) $$d\rho_0 = \zeta t ,$$

where t is a scalar to be determined.

Applying the first of (17) we get for $\rho = \rho_0$:

(24) $$\rho_0 + \zeta t - (\rho_1 + d\rho_1) = p(\rho_0 - \rho_1)p^{-1} .$$

Transforming this by (5) and multiplying by p^{-1}, we get

$$\frac{1}{2 \sin u} p^{-1}(\zeta t - d\rho_1) = \mathrm{V}\zeta(\rho_0 - \rho_1) .$$

By this equation $\mathrm{S}\zeta(\rho_0 - \rho_1)$ remains indeterminate. We represent this scalar by $-z$ and add member to member

$$-z = \mathrm{S}\zeta(\rho_0 - \rho_1) .$$

Multiplying the sum by $-\zeta$ we get

$$\zeta z + \frac{p^{-1}}{2 \sin u}(-\zeta^2 t + \zeta d\rho_1) = \rho_0 - \rho_1 .$$

Taking first the scalar of both members gives

(25) $$t + \mathrm{S}\zeta d\rho_1 = 0 ,$$

so that t is determined by this relation, and there remains

(26) $$\rho_0 = \zeta z + [\rho_1 + \frac{p^{-1}}{2 \sin u} \mathrm{V}.\zeta d\rho_1] .$$

By this expression we see that ρ_0 represents the vector of any point of a straight parallel to ζ (z being an indeterminate scalar), and passing through a definite point, of which the vector depends on p and on ρ_1 and $d\rho_1$, all the elements of which are given, or supposed to be given.

Subtracting (24) member to member from (22) in which we replace ρ' by $\rho + d\rho$, and ρ'_1 by $\rho_1 + d\rho_1$, we get

(27) $$d\rho = \zeta t + d\sigma\,,$$

where we put

(28) $$d\sigma = [p(\rho - \rho_0)p^{-1} - (\rho - \rho_0)]\,.$$

The displacement $d\rho$ is therefore represented by two components. The first, which is parallel to ζ, is the same for all the points, because (27) gives, by $S\zeta d\sigma = 0$,

$$S\zeta d\rho = -t\,,$$

and, by (25), the value of t depends on the data alone, and is therefore a constant. In fact, by this last relation we have the series of equations

(29) $$-t = S\zeta d\rho_1 = S\zeta d\rho_2 = S\zeta d\rho_3 = \&c.,$$

which show that the displacements of all the points of the system, when projected on the direction ζ give one and the same projection, so that we may continue to designate ζt by $d\rho_0$ as by (23 *bis*).

The component $d\sigma$ is perpendicular to ζ, because, owing to $\zeta p = p\zeta$, we have

$$S\zeta p(\rho - \rho_0)p^{-1} = Sp^{-1}p\zeta(\rho - \rho_0) = S\zeta(\rho - \rho_0)\,.$$

Hence,

$$S\,.\,\zeta d\sigma = 0\,.$$

This relation assigns to $d\sigma$ a plane perpendicular to ζ. As to the direction of $d\sigma$ within that plane, we must deduce it from (28). By its definition, $d\sigma$ represents the displacement of $\rho - \rho_0$ after a conical rotation round the axis parallel to ζ, which passes through the point ρ_0, and which therefore is the straight line (26) representing the locus of ρ_0; the angle of rotation being $2u$, namely, twice the angle of p, when

$$p = \cos u + \zeta \sin u\,.$$

We may transform $d\sigma$ in many ways. As, for example, putting

$$\rho - \rho_0 = \sigma\,,$$

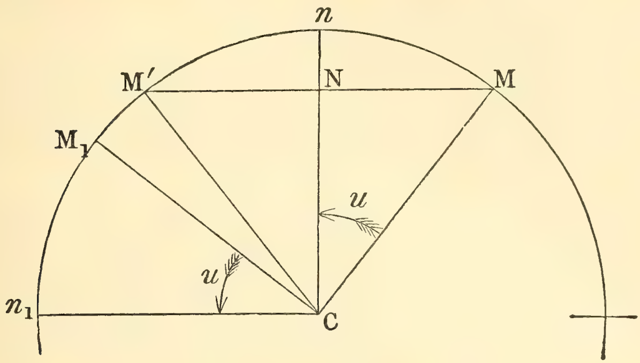
we have

(30) $$d\sigma = p\sigma p^{-1} - \sigma\,.$$

Applying (5), we get

(31) $$d\sigma = 2 \sin u\,.\,pV\zeta\sigma\,.$$

If $\overline{CM}$ represents the projection of σ on a plane perpendicular to ζ (and we assume ζ to be perpendicular to the paper and the positive part of ζ above it), then $\overline{CM_1}$ perpendicular to $\overline{CM}$, M_1 being



on the circumference of the circle of radius CM, and to the left of CM, will represent $V.\zeta\sigma$. Taking $M_1Cn_1 = u$, n_1 being on the circumference, we get

$$\overline{Cn_1} = pV.\zeta\sigma .$$

This gives the direction of $d\sigma$. We then draw the chord $\overline{MM'}$ parallel to $\overline{Cn_1}$, and CN perpendicular to the chord, so that the angles

$$MCN = M_1Cn_1 = u ,$$

and therefore the length $\overline{MN} = Cn_1 \times \sin u$. Hence we have

$$d\sigma = 2\overline{MN} = \overline{MM'}.$$

This construction is more laborious than the one which represents $d\sigma$ when expressed by

(32) $$d\sigma = (p^2 - 1)V(V\zeta\sigma . \zeta) ,$$

where $V(V\zeta\sigma . \zeta)$ represents $\overline{CM}$, the projection of σ on the plane perpendicular to ζ, and where $p^2V.(V\zeta\sigma . \zeta)$ represents $\overline{CM'}$, namely, the result of the rotation of $\overline{CM}$ to the amount of twice the angle of p round the axis ζ.

The two components of $d\rho$ produce, as it is now seen, a displacement which would take place if the system was invariably connected with a screw which, in moving in its nut, displaces itself along the axis of the screw to a distance ζt, while the screw turns

round its axis by an angle $2u$. The pitch h of the screw being

$$\frac{t}{2u} = h .$$

The displacement, according to the first solution, is therefore appropriately called a *screw-rotation.*

When the angle of rotation is infinitely small, then the versor p in the expression (31) reduces itself to unity, and if we designate by ϵ the instantaneous axis of rotation $\zeta \times 2u$, we get by (27) and (31)

$$(33) \qquad d\rho = \epsilon h + V\epsilon(\rho - \rho_0) .$$

In the expression (27) of the *finite* displacement $d\rho$, we may consider now the *data* to be the *six* following scalar elements :—

The *two* which determine ζ; the *two* which determine the position of the axis of the screw by the point where it intersects a plane perpendicular to ζ passing through the origin O of the vectors ρ, this point being

$$V(V\zeta\rho_0 \,.\, \zeta) \text{ or } V\,.\,(\zeta V\,.\,\rho_0\zeta) ,$$

(the part $-\zeta S\zeta\rho_0$ disappearing in the expression of $d\rho$); and, finally, the angle u and the value of t, forming the last *two* elements.

Likewise the expression (33) depends on the three scalar elements contained in ϵ, on the two which determine $V(V\zeta\rho_0 \,.\, \zeta)$, and finally on h, six elements in all.

§ 4.

For the discussion of the second solution we will write the first of the expressions (20) under the form

$$(34) \qquad d\rho - d\rho_1 = 2\eta S\eta(\rho - \rho_1) .$$

We will look upon $d\rho_1$ and η as the principal *data* by which to determine the displacement $d\rho$ of any point ρ, when of course ρ_1 and ρ are given.

Let us determine the point ρ_c, or locus of points, for which the displacement is perpendicular to η. The condition will be (analogous to (23)) for $\rho = \rho_c$,

$$(35) \qquad S\eta d\rho_c = 0 .$$

Writing (34) for $\rho = \rho_c$, we get

$$(36) \qquad d\rho_c - d\rho_1 = 2\eta S\eta(\rho_c - \rho_1) .$$

Treating this by $S\,.\,\eta$ we get, by (35),

$$(37) \qquad - S\eta d\rho_1 = - 2S\eta(\rho_c - \rho_1) ;$$

or if we represent by C the known quantity,

$$C = -S\eta(\rho_1 + \tfrac{1}{2}d\rho_1),$$

we get for the locus of ρ_e,

(38) $$S\eta\rho_e + C = 0.$$

This represents a plane perpendicular to η, its distance from the origin O of the vectors ρ being $= \eta C$.

The value of $d\rho_e$ becomes, by (36) and (37),

$$d\rho_e = d\rho_1 + \eta S\eta d\rho_1,$$

or,

$$d\rho_e = V(V\eta d\rho_1 . \eta),$$

namely, a vector perpendicular to η, as we intended it to be, and known, η and $d\rho_1$ being given.

If we subtract (36) member to member from (34) we get now

$$d\rho = d\rho_e + d\tau,$$

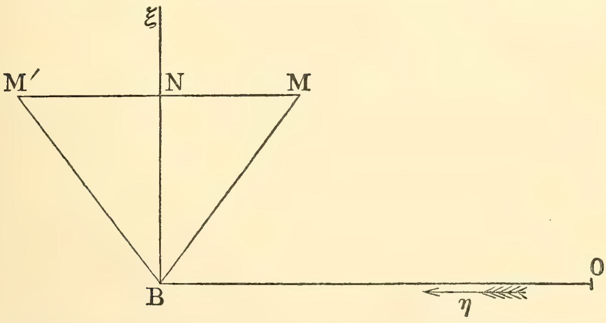
where we put

$$d\tau = 2\eta S\eta(\rho - \rho_e).$$

The displacement $d\rho$ is thus represented by two components at right angles to each other: $d\rho_e$ being constant for any point ρ, and $d\tau$ representing the double of the distance of the extremity of ρ from the plane (38) in which the extremity of ρ_e is situated.

As ρ_e is arbitrary in this plane, we may take ηC in its place, so that

$$d\tau = 2\eta S\eta(\rho - \eta C) = 2\eta(S\eta\rho + C).$$



If BM be the projection of $\rho - \eta C$ on a plane passing through O and containing the direction η, and if $B\xi$ represents in the plane of projection the intersection with the plane (38), then $MN = \eta S\eta(\rho - \eta C)$ and $d\tau = 2\overline{MN} = \overline{MM'}$.

The points M and M′ at both extremities of $d\tau$ are therefore sym-

metrical in respect to the plane (38), and we will call therefore that plane the *plane of symmetry.* The component $d\tau$ having displaced the point ρ into its position of symmetry $\rho + d\tau$, the component $d\rho_e$ parallel to that plane (because perpendicular to η), and being applied to every point, will shift the system of points $\rho + d\tau$ out of their position of symmetry in causing them to move by a translation parallel to that plane, definite in direction and distance. We may designate the result of both the displacements $d\tau$ and $d\rho_e$ by the name of *perversion.*

For the second solution we have also the expressions (3) which we may write now for p and q co-axial (by 11) and apply to

$$\alpha = \rho_1 - \rho_c, \quad \beta = \rho - \rho_c,$$
$$\alpha' = \rho'_1 - \rho'_c, \quad \beta' = \rho' - \rho'_c.$$

We will now determine the angles u and v of respectively p and q. Having

$$(39) \qquad \begin{cases} \alpha' = p\alpha p^{-1}, \\ \beta' = q\beta q^{-1}, \end{cases}$$

we get, by (5) and (20),

$$(40) \qquad \begin{cases} d\alpha = 2\sin u \,.\, p\mathrm{V}\zeta\alpha = 2\eta\mathrm{S}\eta\alpha, \\ d\beta = 2\sin v \,.\, q\mathrm{V}\zeta\beta = 2\eta\mathrm{S}\eta\beta. \end{cases}$$

Treating these relations by $\mathrm{S}\,.\,\zeta$ we get, as the second members vanish,

$$(41) \qquad \begin{cases} \mathrm{S}\zeta d\alpha = 0, \\ \mathrm{S}\zeta d\beta = 0, \end{cases}$$

and consequently also

$$\mathrm{S}\zeta\eta = 0,$$

Thus ζ must be in a plane perpendicular to η. We call ξ the unit-rector perpendicular to ζ and to η, so that

$$\eta\zeta = \xi,$$

and the system ξ, η, ζ will be trirectangular, ξ being also in the same plane with ζ, and to the left of it when seen from a point of the positive direction of η. Let us take the origin of that system at the extremity of ρ_c in the plane of symmetry (38).

In treating (40) by $\mathrm{V}.\zeta$, and remarking that $\zeta p = p\zeta$, and that $\mathrm{V}\zeta p\mathrm{V}\zeta\alpha = p\mathrm{V}\zeta\mathrm{V}.\,\zeta\alpha$, we get (by a change of sign, in replacing $\mathrm{V}.\zeta\alpha$ by $\mathrm{V}.\,\alpha\zeta$)

$$2\sin u\,.\,p\mathrm{V}(\zeta\mathrm{V}\alpha\zeta) = 2\xi\mathrm{S}\eta\alpha,$$
$$2\sin v\,.\,q\mathrm{V}(\zeta\mathrm{V}\beta\zeta) = 2\xi\mathrm{S}\eta\beta.$$

We put
$$V\zeta V\alpha\zeta = \bar{a}$$
$$V\zeta V\beta\zeta = \bar{\beta},$$
remarking that $\bar{a}$ and $\bar{\beta}$ represent the projections of α and β respectively on a plane perpendicular to ζ, namely, on the plans $\xi\eta$, we get, by comparison

$$\frac{2 \sin u}{2S\eta\alpha} \cdot p\bar{a} = \frac{\sin v}{S\eta\beta} q\bar{\beta} = \xi .$$

This gives separately

$$(42) \qquad \begin{cases} pU\bar{a} = \xi\left(\dfrac{S\eta\alpha}{\sin u}\right), \\ qU\bar{\beta} = \xi\left(\dfrac{S\eta\beta}{\sin v}\right). \end{cases}$$

And we must attribute to the second members the signs respectively of $S\eta\alpha$ and of $S\eta\beta$, to be determined in each particular case. In all cases we have

$$\begin{cases} \sin u = T.\, S\eta\alpha \\ \sin v = TS\eta\beta . \end{cases}$$

So that the signs of $S\eta\alpha$ and of $S\eta\beta$ give the signs of the second members of (42).

The number of arbitrary elements, by which the displacement $d\rho$ of any point ρ may depend, will also be six in the most general solution. Having, namely,

$$(43) \qquad d\rho = d\rho_c + 2\eta S\eta(\rho - \rho_c) ,$$

and

$$(44) \qquad d\rho = d\rho_c + 2 \sin u \,.\, PV\zeta(\rho - \rho_c) ,$$

we may consider ρ_c as given by ηC which contains *three* elements, two included in η, and one in C. Then η being given we have ζ by *one* more arbitary element, because ζ already has to satisfy two scalar equations,

$$S\eta\zeta = 0 \text{, and } \zeta^2 = -1 .$$

When η and ζ are determined, then ξ will be known by

$$\xi = \eta\zeta .$$

Finally, the value of $d\rho_c$ is of the form

$$d\rho_c = \xi a + \zeta c ,$$

where a and c constitute *two* more arbitrary elements: in all, six arbitraries, all of them entering in both the expressions (43) and (44).

It is true that in the case of one perversion one might define ζ so as to render $d\rho_c$ parallel to it, and so we would have $a=0$, and there would be only *five* arbitraries; but if we want to combine two given perversions, we are not free to dispose of the direction of ζ arbitrarily.

§ 5.

The results of the two preceding paragraphs will now be applied to the demonstration of the proposition according to which two perversions applied in succession to a given system of points produce a displacement represented by a screw-rotation.

This proposition may be looked upon as known already, but its demonstration in its greatest generality by the quaternion method has perhaps not yet been given.

We assume that the planes of symmetry corresponding to the two perversions have been determined and brought under the form

$$S\eta\tau + C = 0, \quad S\eta'\tau' + C' = 0.$$

We assume also that ρ_c, ρ'_c, ρ''_c be taken so as to assign to ρ'_c a position *on* the line of intersection of the two planes. Let moreover ρ_1, ρ, represent the vectors of two points given arbitrarily before the displacement, and let ρ'_1 ρ^1 be the vectors of these points after the first perversion and ρ''_1, ρ'' the vectors of the same points after the second perversion. Then putting

$$\alpha = \rho_1 - \rho_c, \; \alpha' = \rho'_1 - \rho'_c, \quad \alpha'' = \rho''_1 - \rho''_c,$$
$$\beta = \rho - \rho_c, \; \beta' = \rho' - \rho'_c, \quad \beta'' = \rho'' - \rho_c'',$$

we may represent the perversions by

$$\alpha' = p\alpha p^{-1}, \quad \alpha'' = p'\alpha' p'^{-1},$$
$$\beta' = q\beta q^{-1}, \quad \beta'' = q'\beta' q'^{-} .$$

Hence if we put

$$p'p = p_1, \quad q'q = q_1,$$

we have

$$\alpha'' = p_1 \alpha p_1^{-1},$$
$$\beta'' = q_1 \beta q_1^{-1}.$$

Looking upon $\alpha'' - \alpha = d_1\alpha$, $\beta'' - \beta = d_1\beta$ as representing any displacements, we apply the conditions I. and II. of § 1 in order to determine the nature of these displacements. Generally then they must satisfy the equation

(46) $$\mathrm{T}(\mathrm{V}q_1^{-1}p_1)\mathrm{TV}(d_1\alpha d_1\beta) = 0\,.$$

Let us examine the second factor. We have as to α,

$$d_1\alpha = \alpha'' - \alpha = (\alpha'' - \alpha') + (\alpha' - \alpha) = d\alpha' + d\alpha\,.$$

Thus

$$\mathrm{V}(d_1\alpha d_1\beta) = \mathrm{V}(d\alpha + d\alpha')(d\beta + d\beta')\,.$$

But separately $d\alpha$ with $d\beta$ on the one hand, and $d\alpha'$ with $d\beta'$ on the other, give *perversions* by hypothesis. We have therefore

$$\mathrm{T.V}d\alpha d\beta = 0, \quad \mathrm{T.V}d\alpha' d\beta' = 0.$$

Thus we get

$$\mathrm{V}(d_1\alpha . d_1\beta) = \mathrm{V}.d\alpha'.d\beta + \mathrm{V}.d\alpha d\beta'.$$

Now let us consider the displacements $d\alpha$, $d\beta$, &c., under their other form (19),

$$d\alpha = 2\eta\mathrm{S}\eta\alpha\,, \quad d\alpha' = 2\eta'\mathrm{S}\eta'\alpha'\,,$$
$$d\beta = 2\eta\mathrm{S}\eta\beta\,, \quad d\beta' = 2\eta'\mathrm{S}\eta'\beta'\,.$$

These give

$$\mathrm{V}d\alpha' d\beta = 4\mathrm{V}\eta'\eta\mathrm{S}\eta'\alpha'\mathrm{S}\eta\beta\,,$$
$$\mathrm{V}d\alpha d\beta' = -4\mathrm{V}\eta'\eta\mathrm{S}\eta'\beta'\mathrm{S}\eta\alpha\,.$$

Taking the sum, and remarking that $\alpha' = \alpha + d\alpha$, $\beta' = \beta + d\beta$, we get for the factor of $4\mathrm{V}\eta'\eta$,

$$\mathrm{S}\eta'[(\alpha + 2\eta\mathrm{S}\eta\alpha)\mathrm{S}\eta\beta - (\beta + 2\eta\mathrm{S}\eta\beta)\mathrm{S}\eta\alpha]\,,$$
$$= \mathrm{S}.\eta'\alpha\mathrm{S}\eta\beta - \mathrm{S}\eta'\beta\mathrm{S}\eta\alpha\,,$$
$$= \mathrm{S.V}\eta\eta'\mathrm{V}\alpha\beta\,.$$

So that

$$\mathrm{V}d_1\alpha d_1\beta = 4\mathrm{V}\eta'\eta\mathrm{S.V}\eta\eta'\mathrm{V}\alpha\beta\,.$$

Generally this result cannot vanish, because β which is $\rho - \rho_c$ can be any vector.

As this factor of (46) cannot vanish, we must have

(47) $$\mathrm{TV}(q_1^{-1}p_1) = 0,$$

a solution which gives a *screw-rotation*, the operators

(48) $$p_1(\quad)p_1^{-1} \text{ and } q_1(\quad)q_1^{-1}\,.$$

becoming identical, because the ambiguity $p_1 = \pm q_1$ disappears in the expression of the operator.

Having arrived at the condition (47), by way of exclusion we will now prove by a direct method the identity of the two operators (48).

In the preceding deductions we have admitted that p and q have the same axis, situated in a plane perpendicular to η, this plane having the definite position of the plane of symmetry. Likewise, we have also admitted that the axis of p' and q' be situated in the plane of symmetry corresponding to the second perversion. As these two planes generally intersect each other, we take the direction of the line of intersection for the axis ζ of the four versors p, q, p', q'. We have then

$$S\zeta\eta = 0, \quad S\zeta\eta' = 0,$$

and in putting

$$\eta\eta' = -\cos w + \zeta \sin w, \tag{49}$$

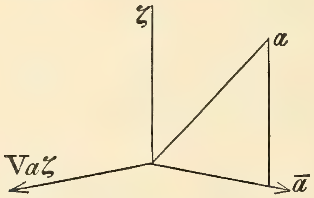
we assume that the positive half of ζ will be directed so as to have η' on the left of η, when the angle w be positive and not outpassing two right angles. Having

$$\alpha' = p\alpha p^{-1}, \quad \alpha' p = p\alpha,$$

whence we deduce $S\zeta\alpha' = S\zeta\alpha$, and putting

$$\bar{\alpha} = V(\zeta V\alpha\zeta), \quad \overline{\alpha'} = V(\zeta V\alpha'\zeta),$$

where $\bar{\alpha}$ and $\overline{\alpha'}$ represent the projections of α and α' on a plane perpendicular to ζ, we get



$$\overline{\alpha'} p = p\bar{\alpha}.$$

This gives $T\alpha' = T\bar{\alpha}$. Hence by (42) we have

$$\overline{\alpha'} p = \xi \frac{S\eta\alpha T\overline{\alpha'}}{\sin u}.$$

Likewise we get, applying (42),

$$p\overline{\alpha'} = \xi' \frac{S\eta'\alpha' T\overline{\alpha'}}{\sin u'}.$$

Multiplying member to member and observing $\overline{(\alpha')}^2 = -(T\alpha')^2$, we get

$$p'p = -\xi'\xi.\frac{S\eta'\alpha' S\eta\alpha}{\sin u' \sin u}.$$

But the same calcul, proceeding from $\beta' q = q\beta$, will establish

$$q'q = -\xi'\xi\frac{S\eta'\beta' S\eta\beta}{\sin v' \sin v}.$$

Both results give the same operator

$$\xi'\xi(\quad)\xi\xi',$$

whatever the signs of the scalar factors may be in the particular expressions of $p'p$ and $q'q$.

Having $\xi = \eta\zeta = -\zeta\eta$, and $\xi' = \eta'\zeta$, we get

$$\xi'\xi = \eta'\eta.$$

We have already defined $\eta\eta'$ by (49). From that definition we deduce

$$(50) \qquad \eta'\eta^{-1} = \cos w + \zeta \sin w = r,$$

so that the operator will have the canonical form. We have thus:

$$(51) \qquad \rho'' - \rho''_c = r(\rho - \rho_c)r^{-1}$$

for all possible values of ρ.

The angle w is evidently by (50) the angle comprised by the two planes of symmetry, the angle of rotation being $= 2w$.

Let us determine the position of the axis of rotation. By the expression (26), in which we change

$$\rho_1 \text{ into } \rho_c,\ d\rho_1 \text{ into } \rho''_c - \rho_c =$$

$$= (\xi a + \zeta c) + (\xi a' + \zeta c'),$$

and u into w, p into $r = \eta'\eta^{-1}$, we get:

$$\rho_o - \rho_c = \zeta z + \frac{r^{-1}}{2\sin w} V\zeta(\rho''_c - \rho_c).$$

Now we have

$$V\zeta(\rho''_c - \rho_c) = \eta a + \eta' a'.$$

Hence

$$\rho_o - \rho_c = \zeta z + \tfrac{1}{2}\left[\frac{\cos w}{\sin w}(\eta a + \eta' a') + (\xi a + \xi' a')\right].$$

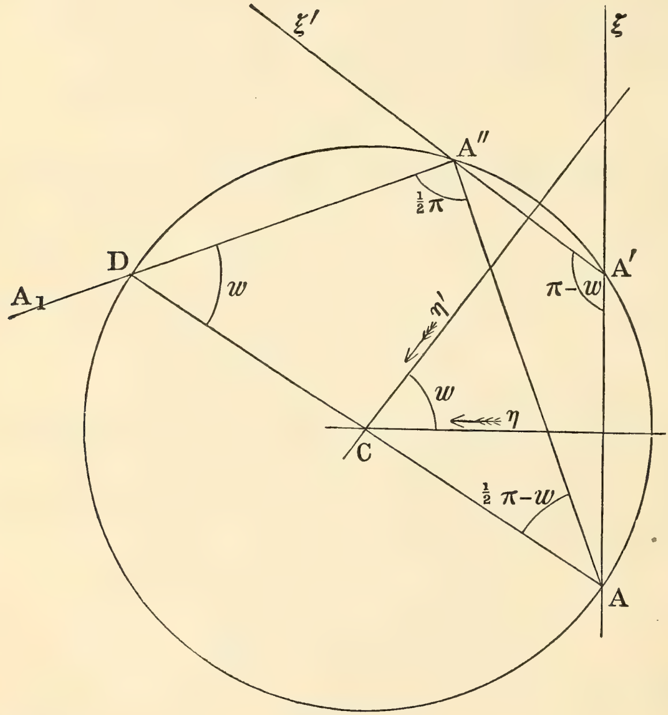
If we represent ξa by $\overline{\mathrm{AA}'}$, $\xi' a'$ by $\overline{\mathrm{A'A''}}$, then

$$\xi a + \xi' a' = \overline{\mathrm{AA''}};$$

also
$$\eta a + \eta' a' = \zeta \overline{\mathrm{AA''}} = \overline{\mathrm{A''A_1}},$$

namely at right angles to $\overline{\mathrm{AA''}}$, and of equal length. To construct $\frac{\cos w}{\sin w}\overline{\mathrm{A''A_1}}$ we describe the circle passing through the three points A, A′, and A″, and the point D where $\mathrm{A''A_1}$ meets the circumference will give

$$\overline{\mathrm{A''D}} = \frac{\cos w}{\sin w}\overline{\mathrm{A''A_1}}.$$



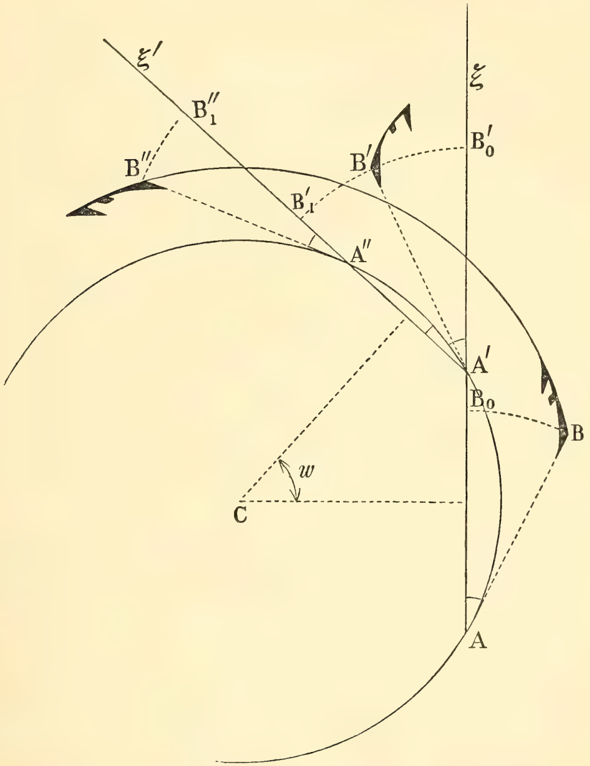
This is because the angle ADA″ is supplementary to the angle AA′A″, which itself is supplementary to w; and as the triangle AA″D is rectangular in A″ by construction, we have, for the length $\mathrm{AA_1} = \mathrm{AA''}$,

$$\mathrm{A''D} = \cot w . \overline{\mathrm{AA_1}} = \frac{\cos w}{\sin w}(\eta a + \eta' a'),$$

therefore

$$\begin{aligned}\rho_o - \rho_c &= \zeta z + \tfrac{1}{2}(\overline{\mathrm{AA''}} + \overline{\mathrm{A''D}}) \\ &= \zeta z + \tfrac{1}{2}\overline{\mathrm{AD}} = \zeta z + \overline{\mathrm{AC}}\,,\end{aligned}$$

C being the centre of the circle, because AD is a diameter. In fact the construction reduces itself practically to the determination of the centre C of the circumference passing through A, A′A″; the



axis of rotation being then a line passing through C and being perpendicular to the plane which is parallel to η and η' the normals of the planes of symmetry.

BUSINESS.

The following Candidates were balloted for and declared duly elected Fellows of the Society:—Dr P. M'Bryde, F.R.C.P. Ed.; Mr G. W. W. Barclay; and Mr Thomas Andrews, F.C.S.

Monday, 16th April 1883.

Mr JOHN MURRAY in the Chair.

The following Communications were read:—

1. On some Properties of the Line of Simple Flexure. By Edward Sang, C.E. (Plates I.*–III.)

The unrestricted problem, "To find the form assumed by an elastic system when subjected to known strains," is one of those mechanical problems which baffle the powers even of the modern calculus. It is only when the change of form is exceedingly small that we can obtain approximate results. In the simplest case—that of a straight uniform elastic body—there is, so far as I know, no complete solution; and thus I venture to suppose that the following remarks may not be devoid of interest:—

If a thin flat rectangular plate—a physical line, as it were—be bent by means of a string attached to its two ends, it takes a particular form, to which the name "curve of simple flexure" may be given.

From the nature of the case, it is clear that if ABC represent the bent plate and AC the string, the curve must be symmetric from the two ends; so that if B be the middle of the bow and BO the ordinate therefrom, the two parts AOB, COB must be alike. Farther, if a second spring of the same dimensions, and bent by a string of the same length, were placed endways to this one, as at CDE, the strings AC, CE being in one straight line, but the bend being on the other side thereof, the ends may be conceived as united at C, so as to form a continuous elastic plate, while the cord may be supposed attached to the two ends A and E.

The same kind of extension may be continued indefinitely both ways; and thus it follows that the curve of simple flexure is com-

posed of an endless succession of equal waves, disposed alternately on either side of a straight line. It belongs, then, to the class of transcendental curves typified by the curve of sines.

Instead of the string we may put two obstacles, one at each end, against which the spring may press. It is obvious that the arrangement ABCDE would be one of unstable equilibrium, so that some slight guide would need to be placed at C, in order to prevent the spring from flying to the one or to the other side.

When the bending is slight, as shown in the first figure (Plate I.*), the form bears a considerable resemblance to that of the curve of sines when flattened to the same degree; but when the flexure is considerable, as in the second figure, the deviation from that form becomes marked; the angle of crossing at the points A, C, E, necessarily is increased. The third figure shows the form of the spring, with its continuation, when the ends are so drawn together, as that the curve crosses the axis squarely.

In the fourth figure the spring is shown as so much bent that the angle of crossing is obtuse; the distance between the ends is less than the breadth of the loop at its widest part. In the actual figure this distance is less than half of the breadth, and hence the continuations of the loops intersect each other.

When the ends are brought still nearer the loops come to cross each other more frequently.

The fifth figure shows the form of the spring when the two ends are brought together. In this case the continuations of the form are all included in its counterpart on the other side and in itself.

When the ends of the spring are crossed over each other, it takes the form of what is technically called a *kink*, as shown in the sixth figure. There the distance of the ends is less than half the width of the loop, and the continuations intersect each other. If that distance were augmented the loops would stand detached.

In these changes we have a noteworthy instance of the danger of abstract reasoning as to limits. While the point C is being brought nearer to A, the number of undulations of the curve within the limits of the sheet increases, so much so, that if C were very close to A, the paper would be covered by a multitude of lines, which, however fine they may be, would tend to produce blackness.

If, after the spring has been crossed, we allow C to come back to

A, we shall have a corresponding increase in the number of undulations comprised within the limits of the sheet; the tendency again being toward blackness. On making the approach from either side, that is, on taking the functions of $a+\delta a$ and of $a-\delta a$, and attributing to the variations δa an infinitesimally small value, we find, on both sides, the functions to be black; yet, on making δa absolutely zero, we find whiteness instead of blackness.

Such being the general features of the curve, we may obtain its details by an examination of one of the half-waves, such as AOB. For this analysis it will be most convenient to place the origin of co-ordinates at the point O. We shall therefore write—

$y=\mathrm{OH}$
$x=\mathrm{HP}$
$l=$ arc BP
$r=$ radius of curvature at P
$a=$ inclination of curve at P
$s=$ surface BOHP.

We shall also write—

$\mathrm{Y}=\mathrm{OA}$
$\mathrm{X}=\mathrm{OB}$
$\mathrm{L}=$ length of BA
$\mathrm{R}=$ radius of curvature at B
$\mathrm{A}=$ inclination at A
$\mathrm{S}=$ area BAO,

for the limits of these quantities.

Since, in such an arrangement, the angular tension at the point P is proportional to the ordinate HP, the radius of curvature there must be inversely proportional to the same ordinate; and therefore we must have

$$rx=c^2 \quad . \quad . \quad . \quad . \qquad (1)$$

where c is a constant determined by the dimensions of the spring. This equation contains the analytical definition of the curve.

Since, from the nature of curvature,

$$dl=r\,.\,da$$

the generic equation (1) may be written

$$x\,.\,dl=c^2.\,da\,, \quad . \quad . \qquad (2)$$

but

$$dy = \cos a \,.\, dl$$

wherefore

$$x \,.\, dy = c^2 . \cos a \,.\, da\,;$$

but the product $x \,.\, dy$ represents the increment of the area BOHP, wherefore we have

$$S = c^2 . \sin a \quad . \quad . \quad . \qquad (3)$$

whence also

$$S = c^2 . \sin A\,.$$

When the angle A is acute, as in fig. 7, there is no difficulty in interpreting this equation; but when that angle is obtuse, as in fig. 8, we have to observe that, in supposing the point P to move along the curve from B, carrying with it the ordinate PH, the area OBPH increases until P arrive at D, where the curve becomes perpendicular to the axis. Beyond that limit the motion is towards BO, the differential of the area becomes subtractive, and thus, for the point p in the figure, s would represent the surface BPDpHO, while S would stand for the area BPDpAO. And when the spring is crossed so as to take A to the other side of O, as in fig. 9, the surface AFO must be regarded as subtractive, so that the symbol S then stands for the excess of BDF above FOA.

On inserting the value of dl, viz.,

$$-dl = dx \,.\, \sin a^{-1}$$

into the equation (2), we obtain

$$-xdx = c^2 . \sin a \,.\, da$$

which, when integrated, becomes

$$\tfrac{1}{2}x^2 = +c^2 . \cos a + \text{constant}\,.$$

Now, when $x = 0$, a becomes A, wherefore the value of the constant is $-c^2 \cos A$; so that

$$\tfrac{1}{2}x^2 = c^2(\cos a - \cos A)\,, \quad . \quad . \qquad (4)$$

which equation completely determines the relation of a the inclination, to x the ordinate of the curve.

Here we observe that when P is at B, a becomes zero and x becomes X; wherefore

$$\tfrac{1}{2}X^2 = c^2(1 - \cos A)\,, \text{ which gives}$$

$$c^2 = \frac{X^2}{2(1-\cos A)} = \frac{X^2}{4(\sin \frac{1}{2}A)^2} \quad . \quad . \qquad (5)$$

and consequently

$$\left.\begin{aligned}\frac{x^2}{X^2} &= \frac{(\sin \frac{1}{2}A)^2 - (\sin \frac{1}{2}a)^2}{(\sin \frac{1}{2}A)^2} \\ \text{or} \qquad \frac{X^2 - x^2}{X^2} &= \left(\frac{\sin \frac{1}{2}a}{\sin \frac{1}{2}A}\right)^2\end{aligned}\right\} \quad . \quad . \quad (6)$$

If, from O as a centre, we describe the semicircle B Cb (fig. 7), and draw PhQ parallel to the axis, we have $hQ^2 = OB^2 - HP^2 = X^2 - x^2$, wherefore OC : hQ : : sin $\frac{1}{2}$A : sin $\frac{1}{2}a$; and hence if, having made Oc equal to sin $\frac{1}{2}$A to the radius OB, we describe the semi-ellipse Bcb, the portion hq intercepted by it must be equal to sin $\frac{1}{2}a$ to the same radius. Hence, if we draw Qr parallel to Bb, the angle bOr must be $\frac{1}{2}a$; and if we make rn equal to br, the radius On must be perpendicular to the straight line touching the curve at P, or, in other words, the direction of the circumference at n is parallel to that of the curve at P.

Similarly, if a parallel to Bb were drawn through c, and the arc intercepted from b doubled, we should get the limiting position N, where the circumference is parallel to the curve at A, that is to say, the angle bON is equal to the maximum inclination of the curve.

Thus it is easy to obtain, by calculation or by construction, the value of x corresponding to a given inclination, or the inclination corresponding to a given value of x, when OB and the maximum inclination A are known.

We may thus obtain an approximation to the true form of the curve by a graphic process. A number of lines parallel to the axis, and crossing OB, having been drawn, we ascertain the angle at which each of them should be crossed by the curve, and draw a series of short connected lines with their inclinations. In this operation we have our choice among three processes. We may divide the ordinate OB equally, computing the corresponding inclinations; we may divide the inclinations equally, computing the successive values of x; or else we may graduate the quadrant BQC equally. The last-named arrangement is the most convenient of the three.

A still closer approximation may be made by considering the curvature. From equation (5) we at once get the value of c^2, that is, of the product rx, so that the radius of curvature is easily computed; and we are able to compose a series of short circular arcs to

represent the curve very closely. It may be remarked that when A is 60°, the circle osculating the curve at B has O for its centre; and that when the crossing is at right angles, the radius of curvature at the vertex is just one-half of the major ordinate.

Since the whole area ABO is expressed by $c^2 \sin A$, and OBPH by $c^2 \sin a$, we have

$$\mathrm{APH} = c^2(\sin A - \sin a)$$

but

$$\tfrac{1}{2}\mathrm{PH}^2 = c^2(\cos a - \cos A)$$

wherefore

$$2\mathrm{APH} : \mathrm{OB}^2 :: \sin A - \sin a : \cos a - \cos A :: 1 : \tan\frac{A+a}{2},$$

so that

$$2 . \mathrm{ABO} : \mathrm{OB}^2 :: 1 : \tan\frac{A}{2}.$$

And thus, when the crossing is perpendicularly, as in fig. 3, the area of one wave of the curve is just equivalent to the square of the major ordinate.

Equation (4) gives us

$$x = c\sqrt{2}\sqrt{(\cos a - \cos A)},$$

so that the second equation becomes

$$dl = \frac{c}{\sqrt{2}}(\cos a - \cos A)^{-\frac{1}{2}}da,$$

and thus the length BP of the curve is to be got by the integration of this transcendental expression, that is,

$$l = \frac{c}{\sqrt{2}}\int(\cos a - \cos A)^{-\frac{1}{2}}da,$$

or

$$l = \frac{X}{cho A . \sqrt{2}}\int(\cos a - \cos A)^{-\frac{1}{2}}da.$$

If we suppose the plane of the paper to be placed vertically, OB being directed toward the zenith, and if we imagine ON to represent the extreme position of a simple pendulum, the velocity acquired in descending from N to n (Pl. II. fig. 7) would be proportional to $\sqrt{(\cos a - \cos A)}$, and thus the element of time in which an increment da of the arc is passed over would be $(\cos a - \cos A)^{-\frac{1}{2}}da$, and we thus have this remarkably beautiful theorem.

If, on the same plane with the line of simple flexure ABCDE, a circle be described round S, the point of suspension of a supposed pendulum, and if the points, P in the curve and n in the circle, be so related that the directions of the two curves be always parallel to each other, then a uniform motion of P along the curve ABCDE (Pl. III. figs. 10, 11) will be accompanied by an oscillatory motion of n (from N to N′ and back), exactly in imitation of the motion of a pendulum.

In the twenty-fourth and twenty-sixth volumes of the Society's *Transactions*, I have described a very expeditious process for computing the motion of a heavy body along the circumference of a circle, which process, by an obvious modification, enables us to get the integral

$$\int(\cos a - \cos A)^{-\frac{1}{2}} da$$

in any proposed case. Thus we may obtain the length of the curve intercepted from the vertex B to any proposed horizontal line.

It remains for us to investigate the relation of the abscissa y to the inclination. Substituting for x its value, we obtain from the above equation

$$xdy = c^2 . \cos a . da ,$$

$$dy = \frac{c}{\sqrt{2}} \cos a(\cos a - \cos A)^{-\frac{1}{2}} da$$

whence

$$y = \frac{c}{\sqrt{2}} \int (\cos a - \cos A)^{-\frac{1}{2}} \cos a . da ,$$

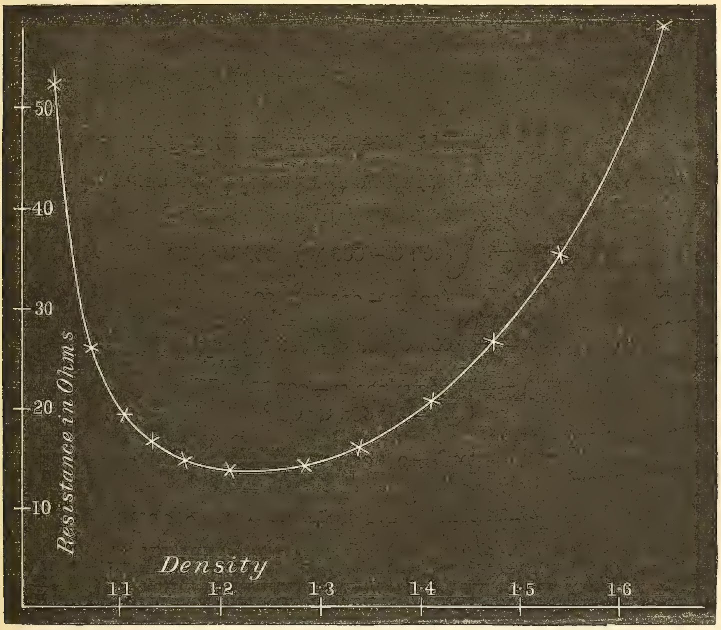
and thus the problem to determine the form of the curve of flexure by help of its co-ordinates resolves itself into a transcendental integration.

2. On the Measurement of Resistance to Electrolytes. By Cargill G. Knott, D.Sc., F.R.S.E.

The difficulties attending the measurement of the electrical resistance of electrolytes are well known, the rapid growth of the polarisation of the electrodes especially preventing the application of the ordinary Wheatstone Bridge method. The polarisation may be kept down by using alternating currents, as was done by Kohl-

rausch; and this method is no doubt the most general and most accurate which has yet been applied.

It occurred to me some years ago that electrometer measurements might give results sufficiently accurate for most practical purposes. To measure the difference of potential between the electrodes by which the current enters and leaves the electrolyte is of course out of the question; but by dipping into the liquid two otherwise insulated platinum points which are connected to the electrometer, we may minimise the effect of polarisation.



The apparatus used in the experiments to be described was constructed fully a year ago, and was simply a horizontal glass tube (11·8 cm. long) fused into the sides of two vertical test-tubes, and having two platinum wires fused into it at points distant 7·3 cm. from each other. The platinum points just projected into the inside of the tube, the bore of which was 0·9 sq. cm. in cross-section. The electrolyte stood in the vertical tubes at a sufficient height to fill the horizontal connecting tube completely; and into the vertical tubes platinum plates were inserted to act as the current electrodes. A current from two Bunsen cells was driven through the electrolyte

and a standard coil of 10 ohms. A rocking commutator permitted the electrodes of the Thomson quadrant electrometer to be connected either to the ends of the standard coil, or to the platinum wires that came from the electrolyte. In this way, a simple comparison of deflections while a steady current was flowing gave the ratio of the resistances of the standard coil and the liquid column between the platinum points.

When the current was kept steadily in one direction, the platinum points became gradually polarised to different potentials; but yet the *difference* between the reading when the current was flowing, and the reading when the current was stopped, was very constant, whatever this latter reading (the approximate zero) might be. By reversing the current from time to time, this polarisation at the points could be kept down; and in no case was the approximate zero ever so great as to show any tendency to fall off appreciably when left for several minutes to itself.

A few preliminary experiments convinced me of the possibility of obtaining results by this method; but it is only within the last few months that a complete series of experiments have been carried out, for which I have to thank Messrs J. W. Macdonald and G. Gregory Smith, students in the Physics Library of the University. These gentlemen investigated very carefully the variation of resistance with density of solutions of sulphuric acid and water at the ordinary temperature (about 10° C.). The following table gives the final reductions:—

Resistance.	Density.
57·87 ohms.	1·647
35	1·540
26·74	1·470
20·57	1·410
15·55	1·340
14·18	1·282
13·9	1·204
14·44	1·164
16·47	1·130
19·36	1·098
25·93	1·069
52·19	1·033

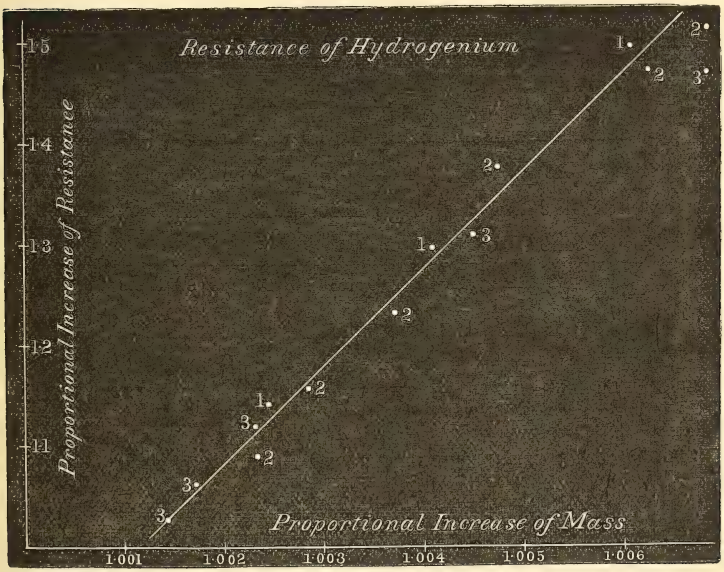
The graphical representation of these numbers gives a good curve, giving 1·23 for the density of the solution of least resistance.

The specific resistances given by these experiments are all considerably too high, and the more so the greater the difference of potential between the points. I think it highly probable, however, that with a longer liquid column, and a stronger current, more accurate values would be obtained.

3. The Electrical Resistance of Hydrogenised Palladium. By Cargill G. Knott, D.Sc., F.R.S.E.

That the electrical resistance of palladium is increased by hydrogenisation has long been known, but the lack of any very definite information induced me to investigate the matter last winter.

In one of Graham's papers in Poggendorff's *Annalen* for 1869,



it is stated that the conductivities of the pure palladium and the hydrogen-charged palladium are as 5·99 to 8·10. Professor Dewar, in a paper in *Trans. Roy. Soc. Edin.*, vol. xxvii., gives the further fact

that the increase of resistance is proportional to the charge, without, however, detailing any particulars.

In the experiments now to be described, the palladium wire was charged by being made the negative electrode of an electrolytic cell. The wire was removed from time to time, and its resistance and mass both measured. The palladium was purified of the hydrogen by being heated to a white heat in a Bunsen flame—a method which, though very effective, was rather destructive to the palladium, which, after several chargings and dischargings, became rent and fissured in an extraordinary manner.

The following are the results of three successive experiments made with the same wire before it became so disfigured as to be practically useless for the purpose. The mass is in grammes, the resistance in ohms :—

Experiment I.—November 27, 1882.

Mass, ...	3·562	3·5702	3·5766	3·5835	3·586
Resistance, . . .	·193	·2215	·2515	·288	·289

Experiment II.—November 28, 1882

Mass, . .	3·559	3·567	3·569	3·572	3·576	3·581	3·583	3·583
Resistance, .	·1865	·204	·218	·232	·2575	·275	·283	·283

Experiment III.—November 29, 1882.

Mass, . . .	3·557	3·562	3·563	3·565	3·573	3·579
Resistance, . .	·1835	·1885	·195	·206	·242	·270

The first member for each row refers to the pure uncharged palladium. Hence, dividing every number by the first in the corresponding row, numbers representing the proportional increase in the mass and resistance will be obtained, and the different experiments made directly comparable. In this way the following table has been prepared, the numbers of the first column referring to the experiment from which the other corresponding numbers have been derived. The numbers of the first row are of course common to all three experiments :—

Experiment.	Mass.	Resistance.
1, 2, 3,	1	1
3,	1·0014	1·027
3,	1·0017	1·062
2,	1·0023	1·094
3,	1·0023	1·122
1,	1·0024	1·148
2,	1·0028	1·169
2,	1·0037	1·244
1,	1·0041	1·303
3,	1·0045	1·319
2,	1·0048	1·381
1,	1·0060	1·494
2,	1·0062	1·474
1,	1·0068	1·499
2,	1·0068	1·518
2,	1·0068	1·518
3,	1·0068	1·472

Graphically represented, these points lie clustered pretty closely round a straight line inclined to the axis, along which mass is measured at an angle whose tangent is ·955, but this straight line does not pass through the origin. Hence it would appear that the resistance does not *begin* to grow so quickly, but that from the point at which the mass has become ·1 per cent. greater than at first the increase of resistance is directly proportional to the increase of mass.

The ratio of the masses of saturated and pure palladium agrees well with Dewar's results. The ratio of the conductivities is almost exactly as 2 to 3, somewhat greater than that cited above.

When the palladium so hydrogenised was used as one element of a simple cell, of which dilute sulphuric acid and platinum were the other elements, the electro-motive force, as measured on the Thomson quadrant electrometer, was found to vary very curiously in relation to the hydrogen charge. The results are given in the following table, the unit mass referring to the pure palladium as above. The second column is the difference of potential in volts between the palladium and platinum poles :—

Mass.	Electro-motive Force.
1	− ·05
1·0014	+ ·81
1·0017	+ ·79
1·0023	+ ·73
1·0045	+ ·74
1·0068	+ ·33

A slight charge of hydrogen makes the palladium strongly positive to the platinum, but this characteristic gradually diminishes till, finally, when the palladium is fully charged with hydrogen, the electro-motive force is less than half its original amount. This fact seems new, and deserves closer study.

4. Note on Plane Algebra. By A. Macfarlane, M.A., D.Sc.

By Plane Algebra I mean what De Morgan called Double Algebra. While ordinary algebra deals with quantities which are represented on a straight line, and Quaternions with quantities which are represented in space, Double Algebra deals with those which are represented on a plane. The object of this paper is to show some applications of this intermediate method.

The quantities considered are conveniently denoted by small Roman letters, leaving their Tensor component to be denoted by the corresponding Italic letter, and the Versor component by the corresponding Greek letter. Thus a denotes a line of length a and angle α; b a line of length b, and angle β. Quantities of this kind are related to those of ordinary algebra as genus and species, and the laws of operation for the former are very easily generalised from those for the latter.

Expansions can be obtained by altering the order of the operations performed; for example, first, by applying the Binomial Theorem and then resolving; and second, by resolving and then applying the Binomial Theorem.

For example—

$$\frac{1}{\mathrm{a}-\mathrm{b}}=\frac{1}{\mathrm{a}}\left(1-\frac{\mathrm{b}}{\mathrm{a}}\right)^{-1}=\frac{1}{\mathrm{a}}+\frac{\mathrm{b}}{\mathrm{a}^2}+\frac{\mathrm{b}^2}{\mathrm{a}^3}+$$

$$=\frac{1}{a}\cos\,(-\alpha)+\frac{b}{a^2}\cos\,(\beta-2\alpha)+\frac{b^2}{a^3}\cos\,(2\beta-3\alpha)+$$

$$+i\left\{\frac{1}{a}\sin\,(-\alpha)+\frac{b}{a^2}\sin\,(\beta-2\alpha)+\frac{b^2}{a^3}\sin\,(2\beta-3\alpha)+\right\}.$$

Again,

$$\frac{1}{\mathrm{a}-\mathrm{b}}=\frac{1}{a\cos\alpha-b\cos\beta+i\,(a\sin\alpha-b\sin\beta)}$$

$$=\frac{1}{a\cos\alpha-b\cos\beta}\left\{1-i\frac{a\sin\alpha-b\sin\beta}{a\cos\alpha-b\cos\beta}\right.$$

$$\left.+i^2\left(\frac{a\sin\alpha-b\sin\beta}{a\cos\alpha-b\cos\beta}\right)^2-i^3\left(\frac{a\sin\alpha-b\sin\beta}{a\cos\alpha-b\cos\beta}\right)^3+\right\}$$

Hence, by equating the components along the initial axis,

$$\frac{1}{a\cos\alpha-b\cos\beta}\left\{1-\left(\frac{a\sin\alpha-b\sin\beta}{a\cos\alpha-b\cos\beta}\right)^2+\left(\frac{a\sin\alpha-b\sin\beta}{a\cos\alpha-b\cos\beta}\right)^4-\right\}$$

$$=\frac{1}{a}\cos\alpha+\frac{b}{a^2}\cos(2\alpha-\beta)+\frac{b^2}{a^3}\cos(3\alpha-2\beta)+ .$$

Another identity is obtained by equating the components along the perpendicular axis.

By treating $(1+\text{a})^{\frac{1}{2}}$ in a similar manner we get

$$1+\frac{1}{2}a\cos\alpha-\frac{1}{2.4}a^2\cos 2\alpha+\frac{1.3}{2.4.6}a^3\cos 3\alpha-$$

$$=(1+a\cos\alpha)^{\frac{1}{2}}\left\{1+\frac{1}{2.4}\left(\frac{a\sin\alpha}{1+\cos\alpha}\right)^2-\frac{1.3.5}{2.4.6.8}\left(\frac{a\sin\alpha}{1+\cos\alpha}\right)^4+\right\}$$

and

$$\frac{1}{2}a\sin\alpha-\frac{1}{2.4}a^2\sin 2\alpha+\frac{1.3}{2.4.6}a^3\sin 3\alpha-$$

$$=(1+a\cos\alpha)^{\frac{1}{2}}\left\{\frac{1}{2}\frac{a\sin\alpha}{1+a\cos\alpha}-\frac{1.3}{2.4.6}\left(\frac{a\sin\alpha}{1+a\cos\alpha}\right)^3+\right\}.$$

An expansion for $\log\{a^2+b^2+2ab\cos\theta\}^{\frac{1}{2}}$ is derived as follows:—

$$\text{Log}\,(\text{a}+\text{b})=\log\text{a}+\log\left(1+\frac{\text{b}}{\text{a}}\right).$$

Now

$$\log\text{a}=\log a+i\log\alpha,$$

and

$$\log\left(1+\frac{\text{b}}{\text{a}}\right)=\frac{\text{b}}{\text{a}}-\frac{1}{2}\left(\frac{\text{b}}{\text{a}}\right)^2+\frac{1}{3}\left(\frac{\text{b}}{\text{a}}\right)^3-$$

$$=\frac{b}{a}\cos(\beta-\alpha)-\frac{1}{2}\left(\frac{b}{a}\right)\cos 2(\beta-\alpha)+$$

$$+i\left\{\frac{b}{a}\sin(\beta-\alpha)-\frac{1}{2}\left(\frac{b}{a}\right)\sin 2(\beta-\alpha)+\quad\right\}.$$

Also

$$\log\{\mathrm{a}+\mathrm{b}\}=\log\left[\left(a^2+b^2+2ab\cos(\beta-\alpha)\right)^{\frac{1}{2}}.\tan^{-1}\frac{a\sin\alpha+b\sin\beta}{a\cos\alpha+b\cos\beta}\right]$$

$$=\frac{1}{2}\log\left(a^2+b^2+2ab\cos(\beta-\alpha)\right)+i\log\tan^{-1}\frac{a\sin\alpha+b\sin\beta}{a\cos\alpha+b\cos\beta}$$

Equate the components along the initial axis, and put $\beta-\alpha=\theta$.

The direct logical power of the method is illustrated by the mode in which it deduces the expressions for the acceleration along and perpendicular to the radius vector for a point moving in any plane curve from the expression for the velocity;

Given

$$\mathrm{r}=r\,.\,\theta$$

$$\frac{d\mathrm{r}}{dt}=dr\,.\,\theta+ird\theta\,.\,\theta\,,$$

then apply that principle again,

$$\frac{d^2\mathrm{r}}{dt^2}=d^2r\,.\,\theta+idrd\theta\,.\,\theta+idrd\theta\,.\,\theta+ird^2\theta\,.\,\theta+i^2rd\theta^2\,.\,\theta$$

$$=\left(d^2r-r(d\theta)^2\right).\,\theta+i(2drd\theta+rd^2\theta)\,.\,\theta\,.$$

5. On Heat-Conduction in Heterogeneous Bodies, as modified by the Peltier and Thomson effects. By Professor Tait.

6. Note on the Thermo-electric Position of Pure Ruthenium. By Professor Tait.

Monday, 7th May 1883.

Professor DOUGLAS MACLAGAN, M.D., Vice-President, in the Chair.

At the request of the Council, Professor Geikie delivered an Address on Recent Advances in European Pleistocene Geology.

BUSINESS.

The following Candidates were balloted for and declared duly elected Fellows of the Society:—Professor Butcher; Mr G. M'Roberts, F.C.S.; Mr R. W. Felkin, F.R.G.S.; and Mr G. Leslie, M.B., C.M.

Monday, 21st May 1883.

MR ROBERT GRAY, Vice-President, in the Chair.

The Chairman read Communications from the Science and Art Department, and from the Education Department.

The Chairman read Obituary Notices of Sheriff Frederick Hallard, Dr John Muir, Friedrich Wöhler, and Sir John Rose Cormack, deceased Fellows of the Society.

The following Communications were read:—

1. On the Moon and the Weather. By John Aitken.

When residing in the south of France lately, I happened to look at the new moon one evening through the clear air of the "Mistral," which was blowing at the time, and not being able to see the dark body of the moon, it all at once struck me that something more was necessary than a clear atmosphere in order to enable us to see the dark side of the moon, and that the dark side would be best seen when the earth was to a great extent covered with clouds.

When we look at the moon when it is a few days old we see that the part of it turned towards the sun is brilliantly illuminated, and that the part in shadow is dark. Further, the degree of illumination of the dark part is known to vary, and is generally supposed to be brightest when our atmosphere is clearest.

Now it is evident that while the sun can illuminate the side of the moon turned towards it, it is quite unable to throw any light on the parts in shadow, as there is no atmosphere or anything round the moon to reflect the light to the shadows. The result is, that so far as the direct rays of the sun are concerned, the dark side of the moon would be quite invisible to us.

If we now transport ourselves in imagination to any part of the moon's surface that is in shadow, we would see our earth like a large moon, which would wax and wane exactly as the moon appears to us, only in the reverse order. When we have no moon on the earth, the earth will appear fully illuminated from the moon; and when we have full moon, the earth will shed no light on the moon. In

addition to these changes in the illumination of the earth as seen from the moon, we would also observe that the brightness of the illuminated part of the earth would vary from time to time, and from point to point. On some days more light would be reflected from the earth to the moon than on other days, giving rise to bright days and dark days. These changes would be produced by the changes in our atmosphere, as it is very obvious that when our atmosphere is covered with clouds more light will be reflected to the moon than when the air is clear and cloudless, as clouds reflect more light than either land or sea. From these considerations we see that the brightness of the dark body of the moon is mainly determined—other things being equal—by the amount of cloud in our atmosphere.

The dark body of the moon being visible, or, as it is generally expressed, "the old moon seen in the arms of the new," is one of our well known and oldest indications of coming bad weather. If the explanation given above of the illumination of the dark side of the moon is correct, then it gives an explanation of the old saying, and we see that this lunar indication, unlike many others, has a sound physical basis. "The old moon seen in the arms of the new" indicates that to the west of us there are at the time vast areas of clouds. Now that is the direction from which we receive most of our weather, and the probability is that many of these clouds are over the North Atlantic Ocean, and will travel eastwards and northwards, and unburden themselves over the north-west of Europe.

If these conclusions are correct, we might look upon the dark side of the moon as an outlying signal station, capable of giving us indications of the more or less cloudy condition of the earth's atmosphere, and with properly constructed instruments, the signals might, with some practice, come to be perfectly intelligible and accurate. There is, however, one unfortunate circumstance which will make the readings of these signals at certain times extremely difficult. The brightness of the dark side of the moon will not only be determined by the more or less cloudy condition of our atmosphere, but also by the amount of the illuminated side of the earth turned towards the moon, and, as this varies from day to day, the interpretation of the signals will be difficult and probably impossible when the moon approaches the full, as the illuminated part of the earth then turned

towards the moon is very small. On the other hand, the diminished illuminated area of the earth turned towards the moon, makes the lunar indications in another way more definite, as the moon then reports the cloudy condition of a much narrower area, east and west, of the earth's surface. Allowance would, of course, require to be made for the more or less clearness of our atmosphere.

If we wish to get the amount of cloud during the last half of the moon, we can observe it as during the first half; but now it will give us the cloudiness to the east and not to the west of us as before. So that if we wish to know the condition of the atmosphere to the west of us over the Atlantics, during the last days of the moon, we must have the observations made and telegraphed to us from America.

These suggestions are here offered in an extremely crude state; but as they appear to have a germ of truth in them, they are offered in the hope that some one with the proper means of observation may take them up and put them to a practical test.

2. The Acids of Opium. By D. B. Dott.

The acids which have been described as existing in opium are meconic, sulphuric, lactic, and acetic acids. It is not certain that the two latter are always present. In any case they exist in small amount, and are of little importance. For many years after its discovery in 1805 by Sertürner, meconic acid was regarded not only as the peculiar acid of opium, but as that with which the morphine and some of the other bases are wholly combined. In later years it has become known that the morphine exists partly as sulphate, but I do not find that any analyses have been made, showing to what extent this is the case. The subject has indeed received but little attention, as is evident from the fact that in many of the most recent publications it is assumed that the morphine exists naturally entirely as meconate.

In 1878 Dr C. J. H. Warden of the Bengal Staff published an interesting analysis * of Behar opium ash, obtained by preserving the ashes of all the samples analysed at the Government Opium Factory for several years. The chief feature of interest in the

* *Chemical News*, xxxviii. p. 146.

analysis is the large percentage (23·14) of sulphuric anhydride found, mostly combined with potash. Mr J. Scott, in his *Manual of Opium Husbandry,* gives analyses of poppy plant ash, in which the sulphuric anhydride varies from 5·93 to 10·08 per cent. Mr Scott points out that the larger the amount of sulphuric acid in the plant, the smaller is the yield of morphia :—

SO_3 in Plant Ash.	Morphia in Opium.
5·93	8·66
7·64	6·47
10·08	4·65

Referring to these results, Dr Warden remarks :—"It would be interesting to ascertain whether or not there is a similar correlation between the SO_3 in the opium ash and the amount of morphia contained in the drug. Possibly the SO_3 in opium may be directly proportionate to its richness in morphia."

In order to determine whether this surmise is correct, the sulphuric anhydride in a number of opiums was estimated by exhausting the drug with water, adding large excess of hydrochloric acid, and then precipitating with chloride of barium. It was found that this method avoided the precipitation of meconate. In the table below are given the percentages of sulphuric anhydride and morphia found in various samples of Turkey and Persian opium. As it cannot be pretended that any process for assaying opium gives absolutely accurate results, the figures under *morphia* are only considered comparative, and as an approximation to the truth.

	SO_3 per cent.	MH_2O per cent.
a,	2·08	8·5
b,	2·01	15·3
c,	1·97	12·3
d,	1·94	12·1
e,	1·74	9·8
f,	1·72	12·2
g,	1·65	7·9
h,	1·50	9·5
j,	1·49	11·1
k,	1·07	2·0

It is evidently impossible to deduce from these results any general

law relating the proportions of sulphuric acid and morphia. The most that can be said is that if an opium is rich in sulphuric acid it will probably be rich in morphine; but the determination of the amount of sulphuric acid could not be used as a means of ascertaining the value of the opium. The interesting fact revealed by these estimations is the large proportion of sulphuric acid existing in opium. So far as I am aware, this has not been previously pointed out. It becomes important to know in what manner the acid is combined. In order to determine this we must know what bases and acids exist in opium. The only alkaloids that need be taken into account are morphine, codeine, thebaine, papaverine, narcotine, and narceine, and of these only codeine and thebaine excel morphine in basic power. The principal mineral base present in opium is, as might be expected, potassium oxide. Biltz, in his careful analyses* of Turkey and of German opium, gives the percentage of potassium sulphate as 2·0 to 2·5. By exhausting fine Turkey opium with water and incinerating the extract, I obtained 2·50 per cent. of ash, which indicated 0·95 $SO_3 = 2{\cdot}06$ K_2SO_4. This confirms Biltz's results. We may safely leave out of consideration all acids except sulphuric and meconic. It might almost be assumed that sulphuric would replace meconic acid in any of the latter's combinations, but to make quite sure, I dissolved a weighed quantity of morphia meconate in water, added an equivalent of standard sulphuric acid, and gently evaporated. When the solution became filled with crystals, these were examined, and found to consist entirely of sulphate. Taking then, the sample (*b*) in the table above given, we find that it yields 15·3 per cent. of morphia hydrate and 2·01 SO_3. Of this amount 0·95 per cent. is in combination with potash and 0·13 per cent. in combination with the stronger alkaloids (as nearly as can be estimated), leaving 0·93 to unite with the morphia. This amount of anhydride is equivalent to 7·04 per cent. of morphia hydrate, or *nearly half the morphia in the opium.* It would be confirmatory evidence if the proportion of meconic acid in opium were found insufficient to neutralise the morphia. This fact is proved by the following experiments:—

(1) 100 grs. of opium, indicating 11·1 per cent. of morphia, were exhausted with water, slight excess of ammonia added, and the solu-

* Buchner's *Repertorium*, xxxix.

tion filtered. The filtrate was rendered faintly acid with acetic acid, and then excess of barium nitrate added. The precipitate, after being washed with the minimum of cold distilled water, was dried in the water-bath, and found to weigh 10·31 grs. This was treated with nitric acid to remove the meconate, and then ignited, leaving 4·36 grs. $BaSO_4$. The 5·95 grs. meconate of barium considered as $C_7H_2O_7Ba.H_2O$ is $= 3·37$ grs. $C_7H_4O_7 = 8·0$ grs. morphia.

(2) From a quantity of good opium the morphia and meconic acid were prepared with as little loss as possible. There were obtained 627 grs. morphia hydrate and 186 grs. crystallised meconic acid. The proportion demanded to form the normal meconate is 262 grs. Experiments with other opiums were conducted as in (1), with similar results, the proportion of meconic acid to morphia being even less than that there described.

It is evident that if the morphia salts could be made to crystallise from a simple extract of opium, much light would be thrown on the matter under discussion. With this end in view, 500 grs. of opium were exhausted with alcohol, the alcohol driven off, and the extract treated with water. The aqueous extract was digested with purified animal charcoal, and then concentrated. After some days, a small quantity of crystals had appeared. These consisted of morphia sulphate. (It should be noted here that while the neutral meconate readily crystallises, the acid meconate has never been obtained in the crystalline state.) This cannot be regarded as an altogether satisfactory experiment, on account of the small yield of sulphate, but considering that the extract is charged with substances which hinder crystallisation, the result is not surprising; the use of any purifying agents which would cause decomposition being, of course, quite inadmissible.

To thoroughly elucidate the question would require an enormous number of experiments; but judging from the facts ascertained, I am of opinion that morphia exists in opium, partly as neutral sulphate and partly as acid meconate.

3. Direct Observations of the Effect of Pressure on the Maximum Density-Point of Water. By Professor Tait.

Monday, 4th June 1883.

Mr ROBERT GRAY, Vice-President, in the Chair.

The following Communications were read :—

1. The Diurnal Oscillations of the Barometer. Part II. By Mr A. Buchan.

2. Ninth Report of the Boulder Committee. Communicated by Mr Milne Home.

I.—*NOTES BY CONVENER.*

Argyleshire.

I. 12*th July* 1882, *Stonefield House, Argyleshire*, residence of C. G. Campbell, Esq.—Was guided by Mr Alexander of Lochgilphead, to the hills of *Glen Ralloch*, situated to the north of the narrow neck of land which connects East and West Loch Tarbert. The rocks of the hills are gneiss, full of quartz veins. When among those hills, I saw many boulders of small size lying on the sides, and some on the very tops. Their composition, resembling clay-slate, differed from the rocks, and they were all more or less angular. They were mostly on slopes facing, or exposed to, westerly points.

On reaching a hill on the north side of West Loch Tarbert, and sloping down due south towards the loch, at an angle of about 40°, and at a height above the sea of 400 feet, fell in with a boulder lying on the surface, $7 \times 5\frac{1}{2} \times 3$ feet. The rock, visible almost directly under, and at all events very close to, the boulder, was a schistose clay-slate, but with a sprinkling of gravel over its outcrop. The boulder could not probably come from the north, as the hill in that direction rises to a height of about 200 feet above the boulder, and is steeper near the top. The directions from which the boulder might most easily have come are S.E., S., or S.W., this last being the line of the arm of the sea called West Loch Tarbert. The hills to the west, and still more to N.W., appeared too high to have allowed the boulder to have come across them.

II. 14*th July* 1882, *Ormsary House* (on south bank of Loch Killesport), *Argyleshire*, residence of Mrs Campbell.—Set out, under the guidance of Mr Alexander, to visit *Clach Briach* (stone-spotted hill), on which he informed me I would find a number of large boulders.

This hill being situated a few miles to the east of Ormsary House we had to pass the "*Big Boulder*" near the high road, described in a previous Report (Sixth, p. 14), and illustrated there by diagram 5.

I was again struck with the fact, that at this spot there is a great multitude of boulders, several of them touching one another. I counted ten, occupying a space less than 2 acres in extent; one of these (apparently not mentioned in the previous Reports) measured 16 × 12 × 8 feet.

Mr Alexander informed me that on the hills along the south side of Killesport, *west of Ormsary House*, there are no boulders; and that they occur only on the hills to the east of Ormsary House, with the exception of two on the sea-beach. The only peculiarity which I discovered in these respective hills was that to the west of Ormsary the sides of the hills facing Loch Killesport are excessively steep, whereas the hills to the east of Ormsary slope more gently to the Loch, and are not so high. If the boulders were brought on floating ice from the W., or W.N.W., would the last-mentioned hills, because of their more gentle slope, not have more readily arrested the ice, and have afforded sites for boulders when the ice melted?

We passed through a valley called *Baronlungart*, running E. and W. between *Ormsary* and *Achoos*. In the bottom of the valley there are several spots where the rocks are beautifully ground down and smoothed, evidently from the westward. This valley is about 60 feet above the sea-level. A few boulders are lying in the valley.

Having reached the shepherd's house, on *Clach Briach* hill, I mounted a horse and followed a peat road for about a mile in a westerly direction, till we reached a level of about 400 feet above the sea, and came to a place from which we could look down to the north on the farmhouse of *Tign-a-Kaim*. The hill, along the ridge of which we had ascended, terminated at this place in a rounded

end, sloping down northward, westward, and southward. The slope most thickly covered with boulders was that sloping to N.W. at an angle of about 40° (see diagram 1). The three largest were of the following sizes:—15 × 8 × 5 feet; 18 × 9 × 8 feet; 12 × 7 × 4 feet.

The boulders are all, more or less, well rounded. The sides most rounded were those facing N.W., suggesting the idea that, after having reached the hill, they had been exposed for some time to friction from some agent impinging on, or passing over, them.

They appeared to be all composed of one description of rock, viz., a compact fine-grained gneiss, which is also the composition of the Ormsary "Big Boulder" and its companions, before referred to. The rocks *in situ* on this *Tign-a-Kaim* hill are soft schist, and on edge.

On the highest part of the hill, and about 20 or 30 yards on the south side (at A on fig. 1), there are several boulders in positions of considerable interest. These are shown on fig. 2. Where boulder A is represented on fig. 2, the ground is nearly flat; at B, the ground begins to slope slightly down south; and at D, the southward slope is as much as 20° or 23°. Boulder D has a girth of about 26 paces, or 78 feet. Its height is about 15 feet. The size of B is 10 × 10 × 10 feet, and of A, 6 × 5 × 3 feet.

It was observed that a fragment had been broken off each of the two largest boulders at their south ends. The form of the fragments and their proximity to the boulders made this evident. There may originally have been cracks in the boulders, allowing rain to enter, and the action of frost to split off the ends. Another conjecture is, that if the boulders, when brought to the hill, fell from any height, and if they had a projecting piece of rock at their south ends, the concussion in the mass, produced by the central solid portion of the boulder first striking the hill, might cause the projecting piece to break off. The direction of the longer axis of the largest boulder D is about W.N.W. and E.S.E.

Not far from these, and also on or close to the highest part of the hill, there are other two boulders (shown on diagram 3) touching one another, A being 17 × 8 × 8 feet, and B 18 × 10 × 10 feet. The direction of the longer axis of A is S.W., and of B, N.W. A small boulder lies between the two, at the north end, firmly jammed. It

seemed probable, from the positions of the boulders, that boulder B was the first to come, and that the others subsequently had been intercepted by B in their further progress eastward.

From this hill the three Paps of Jura, 2500 feet high, are visible, bearing W.N.W. The more distant island of Mull, reaching to a height of 3000 feet, bears N.N.W. If the boulders on Loch Killesport, above described, came from either of these sources, they must have crossed, not only two sounds or arms of the sea, but also the two or three tongues of land which project from this part of the coast of Argyle. Before, however, that suggestion can be favoured, it would require to be shown that the rocks composing the boulders are similar in composition to rocks in Jura or Mull.

To the west of the *Tign-na-Kain* hills, above described, there is another hill, separated from them, by a small valley, on which many boulders are visible, on the side of the hill sloping to the north. This hill is almost 100 feet higher; but I could not ascend it, much to my regret.

18*th July* 1882, *Taynish House*, on Loch Sweyn, the property of Captain Campbell of Inverneil.—The house, garden, and policy are at the point of a narrow tongue of land, on the south side of *Loch Sweyn*, which projects into the loch in a S.S.W. direction. Near the point where this tongue reaches the sea there is on it a ridge, running (by compass) about W. by S., with a breadth of about 100 yards, and rising eastwards to a height of about 100 feet above the sea.

This tongue of land, especially on its higher parts and on its northern slope, is covered by above 50 boulders, the largest of which are of the following sizes:—

$18 \times 11 \times 8$ feet. Its longer axis lies W. by S., and small end to west. It lies on the broken edges of vertical strata, as shown in diagram 4. Its longitudinal axis dips to west, at an angle of about 20°. *r, r, r* are edges of the rocks *in situ* on which the boulder rests.

$15 \times 19 \times 5$ feet. Its longer axis is N.E. and S.W.

$8 \times 4 \times 3$ feet. ,, W. by S.

$8 \times 4 \times 2\frac{1}{2}$,, W. by S. with small end to westward.

$9 \times 6 \times 4$ feet. Its longer axis W. by S.

Diagram 5 is a ground plan of the surface on which these boulders lie,—*b* is about 100 feet above the sea, and *d* about 60 feet; *b*, *d* representing a ridge running about W. by S. and E. by N., with the surface sloping gently down on each side towards the north and south respectively, as shown by arrows and the letters *e*, *f*. Much of this rocky tongue on which the boulders lie has been ground down to a smooth surface.

The site of the largest boulder B represented is shown in diagram 5 on the northern slope at B.

The greatest number of boulders deposited is on the northern slope (diagram *e*, *a*, *b*), as if they had come from some north-westward point, and had been intercepted by the slope.

The position of these boulders, especially of the largest, renders it more probable that they came by floating ice from the sea, than by a glacier from the land.

Learnt from the shepherd's wife, an intelligent woman, residing in the offices of Taynish House, that there are two other large boulders at or near the shore, about 300 yards south of Taynish House; but bad weather prevented a visit to them. In the policy of Taynish, close to the avenue, about half a mile to the east of the house, we observed many boulders on a hill side, sloping down to the north, at about 200 feet above Loch Sweyn.

On our return to Ardrishaig I visited again the large boulder at *Loch Mhurrich*, mentioned in the Sixth Report, p. 16. Ascertained that the depth or vertical thickness of the boulder was, at its east end, 12 feet, and at its west end, 5 feet; its narrowest end being therefore towards the west. Its longer axis, which is W.S.W. and E.N.E., slopes down towards the west.

The situation of this boulder, relatively to the adjoining hills, is shown in diagram 6, where B is the boulder and H rocky hills surrounding the valley, with small boulders scattered over them, shown by dots. These hills rise to the height of from 200 to 300 feet above the sea.

When looking from the boulder towards the west, a range of low hills is seen crossing the valley, about half a mile distant, and in that range a depression occurs, through which the road passes, leading westward to Keills. The summit level of this depression is about 100 feet above the sea, whilst the rest of the range crossing

the valley reaches to a height of from 300 to 350 feet. The bearing of this depression from the boulder is W.S.W., coinciding with the direction of the longer axis of the boulder. If the boulder had been carried to the spot where it now lies, from the westward, it would probably be by ice floating through the depression before referred to. For any land glacier the locality seems quite unsuitable.

On our way back to Ardrishaig we observed, on the hills within sight of the road, many boulders. They lie most frequently on slopes facing some westerly point. Thus, on a hill called "*Leck-na-Ban*," on the north side of the road, at about 300 feet above the sea, where the slope is towards W.S.W. at an angle of about 10°, a boulder 10 × 8 × 6 feet is lying on the edge of vertical strata, the boulder being a light-coloured fine-grained crystalline gneiss, while the rocks on which it lies are a soft slaty schist.

Near the Crinan Canal at *Ballanoch*, on the hill above the high road, and about half a mile from the canal, there is a boulder 16 × 9 × 9 feet, at a height of about 300 feet above the sea. It lies on the north side of the valley through which the road passes. The general direction of the valley is N.E. by N. and S.W. by S. The longest axis of the boulder coincides with the direction of the valley. The boulder is lying on bared rocks. It seemed probable that ice carrying boulders had floated through this valley, and lodged the boulder.

19*th July* 1882, *Ardrishaig Hotel.*—In the Seventh Boulder Report, p. 10, a very partial account was given of smoothed and striated rocks at *Kilmory*, at the western extremity of the tongue of land dividing *Loch Killesport* from *Loch Sweyn.* I therefore returned there, to examine the spot more minutely, in company with Mr Alexander of Lochgilphead.

At *Ardna*, Mr Macmillan's farm, I saw again the large expanse of these interesting rocks.

The extent of rock surface, horizontally, is about 13 yards, and vertically, about 5 yards. The surface in different parts slopes down towards S. by E.—S.—S.S.E.—and S.E., at angles varying from 30° to 40°. They have been most severely rutted, on the slopes which face S. and S. by E. Where the surface slopes down S.E. it is not striated, only smoothed; showing that the striating agent did not

move in such a direction, as to touch or strike, or at all events press severely on the S.E. slope. In some places the striæ were seen to have been more deeply cut at their *west* ends than at their east ends. Some of the striæ at their west ends are as much as 3 inches wide. The direction of the striating agent must therefore have probably been from W. by S., or due west, to have made the striæ. Portions of the smoothed rock surfaces were broken into small shallow depressions, and in these pebbles of hard rocks were observed, somewhat firmly packed, and where probably they have been lying since the time they were originally deposited. It was by such tools as these that the striæ had no doubt been formed on the smoothed surfaces of the rocks. A representation of a few of these striæ, and of the depressions in the rocky surface, is given in diagram 7.

That there must have been heavy pressure on these smoothed rocks, is evident from this fact, that though the rocks are dipping or sloping down towards the south, at an angle of as much as 40°, the striæ are all *horizontal*, or nearly so,—showing that the striating body was of such bulk and weight as to keep steadily on in its course, in spite of the tendency, by gravitation, to slide down the face of the rock.

On the hill where these smoothed and striated rocks occur, boulders of small size (comparatively), and much drift of hard rounded pebbles, are plentiful.

After examining these rocks I climbed the hill to the eastward to a height of about 600 feet, and passed several striated rocks, and three boulders of the following sizes:—$11 \times 7 \times 3$ feet, $12 \times 5 \times 2\frac{1}{2}$ feet, $15 \times 6 \times 4$ feet. Each boulder has its longer axis pointing in the same direction, viz., W.S.W. and E.N.E. These are situated near the top, and on the side of the hill sloping down towards the S.S.E.

Having crossed the ridge of the hill towards the north, and descended a little way on the side sloping down towards N.N.W., I was struck at finding almost all the boulders lying with their longer axis W.N.W. and E.S.E. The following are the sizes of the largest boulders examined:—$11 \times 6 \times 3$ feet (with sharp end to N.W.), $14 \times 8 \times 3$ feet, $14 \times 7 \times 7$ feet (its longer axis was W.S.W.), $21 \times 7 \times 3$ feet, $9 \times 6 \times 4$ feet (its longer axis due west); but here there was a change in the down slope of the hill, viz.,

towards W. by N., instead of N.N.W. This last mentioned boulder was lying not on drift, as the others were, but on bare rock.

A little further east, where the high road passes through the lands of Castle Sweyn, but above the road, and at a level of about 200 feet above the sea, found a group or cluster of boulders, four or five in number, touching and partly covering one another, as shown in diagram 8. The remarkable feature of the spot is, that the slope of the hill here is so steep—about 40°—that it was hardly conceivable how the blocks should, when laid down on such a slope, have remained on it, and have for ages retained their position. The only probable explanation seemed to be, that beneath the two lowest boulders there were portions of projecting rock which supported the whole group. The slope of the hill here is down towards W.N.W. A study of the whole position led to the conclusion that these boulders, to obtain their lodgment, must have been brought from W. by N.

Still farther east the road passes over an extensive plateau or table-land of drift, which has a general height of 120 feet above the sea. The farm of *Doidhe* is here. A gravel pit (almost 8 feet deep) for the excavation of road metal was examined. The layers of gravel and sand in it were found to be horizontal.

All along the road towards *Ashfield*, *Deltot*, and *Achnamara*, large boulders occur on both sides, though not in nearly such numbers, as near the open sea at *Kilmory*, and near *Castle Sweyn*.

20*th July*, *Ardrishaig*.—Was guided by Mr Alexander to the farm of *Ach-na-Brack* (*Field of Spots*) to see some remarkable sculptured cup-markings on smoothed rocks.

These rocks occupy an extensive portion of pasture ground. They are of hard gneiss, and the smoothed surfaces slope down towards about S.W. at an angle of 10° or 12°. They have evidently been smoothed by natural agency. Striæ occur on them at several places. The direction of the striæ varies a little, being in some spots from W. by N., in others from N.W. One small boulder was seen, on the west side of one of the smoothed ridges of rock, and seemed to have been stopped by the rock in its progress eastward.

The cup-markings are very numerous, and consist as usual of circular ruts as shown in fig. 9. They are of different sizes; the largest about 2 feet across. The straight rut issuing from the

centre, and cutting across the circular ruts, had in almost all cases been formed in unison with the downward slope of the rock. There are 20 or 30 of those cup-markings, and they well deserve to be described and sketched. Archæologists have never yet been able to suggest any plausible explanation of the object or meaning of these ancient symbols.

Berwickshire.

August 1882.—Convener received from his factor, Mr Muirhead, a chip of a small dark-coloured syenite boulder, found on Lamberton Hill, four miles north of Berwick, at a height of about 600 feet above the sea. It was found near the summit of the hill, which there forms a ridge running N. and S. It was on the slope of the hill facing the west. The only locality in Berwickshire for syenite rock is Stenchel Hill, on east side of Cockburn Law, distant about 10 miles to W.N.W. The size of the boulder was 30 × 16 × 16 inches, weighing about 20 stones. The whole of Lamberton Hill is a mass of porphyry.

II.—*NOTES BY PROFESSOR HEDDLE.*

1. *Excursion from Killin (Perthshire) up the N. and S. valley of Radour, in Kenmore Parish,—over Heasgarnich,* 3530 *feet, to Loch Lyon,—and thence down the Allt Chonoghlais valley to Tyndrum, accompanied by Rev. Mr Peyton, of Free St Luke's, Broughty Ferry.*

1. In Radour valley is found on the slopes of *Creag nam Bodach*, at altitude of 1400 feet above the sea, a boulder 9 × 7 × 7 feet, of "pure *white quartz*," sharp and angular. The rock of all the hills hereabouts is "*flaggy gneiss.*"

There is such quartz rock on *Creag Mhor* and *Ben Dorean*, situated to the W. and N.W.; also, a quartz rock, though not quite similar, on *Meall Ghaordie* to the east.

2. On the *Heasgarnich* side of the same valley, there is a boulder 13 × 5 × 6½ feet, somewhat more gneissose than the flaggy rock of the district, at an altitude of 1600 feet.

3. Towards the rounded head of the glen, at an altitude of about

1650 feet, there are eight other boulders, averaging $11 \times 5 \times 4$ feet, and forming a line across the valley.

4. The pass at the head of *Loch Lyon* is crowded with *till*, which fills great stretches of the valley. It has been by some means shaped or worn into conical mounds, and abounds from the level of the lake, at 1100 feet above the sea, down to about 800 feet.

2. *Excursion from Killin to Bowachter, in Glen Dochart* (*Perthshire*), *and thence over Sgiath Chrom*, 2780 *feet; Sgiath Chuil*, 3050 *feet; Meall Chuirn*, 3057 *feet; and along the ridge over Meall na Saone*, 2835 *feet, eastward to Mid Hill*, 1977 *feet; accompanied by Professor Butler and Mr Colin Phillip.*

1. On the south side of *Sgiath Chrom*, at altitude of 1520 feet, found two boulders; one in size about a cubic yard, the other $8 \times 5 \times 4$ feet. This last was of hornblendic gneiss with chlorite, similar to a rock seen by me on a previous occasion, between *Ben Laoigh* and *Ben Oss*, situated about 10 miles to W.S.W.

2. On the east side of *Meall Chuirn*, found a valley or trench running N. and E., about 750 feet deep, separating that hill from the ridge to the east. On the east slope of this trench, found some loose rock, apparently not fallen from the upper part or side of the valley, but ice-carried.

3. Proceeding towards the eastward, found three small hills with flattened summits, each over the 2750 contour line, but not named on the Ordnance map. The most northern of these is very precipitous on its sides, and separated from the other two by narrow cols about 80 feet deep. From the top of one of these, which we ascended, we descried a boulder perched on the top of another hill with precipitous sides, lying in a slight depression. The boulder was apparently about 10 feet cube. Considering this boulder, on account of its position, to be one of interest, we retraced our steps about 300 yards, to try and reach the boulder, but were defeated. There was over a foot of newly-fallen snow, which prevented our finding a firm footing, and caused constant and dangerous slipping.

4. Proceeding about three miles farther eastward, towards the *Mid Hill*, 1977 feet, we had to cross a depressed flat surface, now a peat bog, about 200 feet below the top of the hill. The summit

of the hill consists of flattened rock, whose contour "shows unmistakably that its form is the result of a body of ice having passed over it from the west." Its eastern end shows marks of having been broken; and some little space eastward from the cliff there is a great rugged block, which seems to have been detached from the rocky cliff, and pushed a little way eastward.

3. *Excursion from Luib Railway Station northward, over Beinn nan Clach,* 2309 *feet; Bein nan Imirean,* 2500 *feet; Bein Glas,* 3139 *feet; Bein Dheiceach,* 3074 *feet; then down stream-valley, back to Luib;—with Mr Colin Phillip.*

1. Found the whole south side of *Beinn nan Clach* from 2000 to 2100 feet, sprinkled with boulders from 1 to 3 cubic yards in bulk. They consisted of a kind of rock differing from that of the hill, being more chloritic.

Found a line of somewhat larger boulders lying along the top ridge of the hill, stretching in a line towards *Imirean.* Found a much rounded block about two cubic yards in bulk upon the *solid rock of the very summit of the hill,* at a height of 2309 feet above the sea (see fig. 10). The rock of the summit was also much rounded.

Noticed also the outcrop of some nearly horizontal strata, with scattered dislodged fragments; suggesting the action of some moving body which had been grinding on and rupturing the edges of the strata.

Found blocks at about the same, or rather lower level, in the corry between *Beinn nan Clach* and *Beinn Glass,* as also at the foot of the east slope of *Bein Dheiceach;* but these might have fallen from rocky cliffs above them.

During the two last excursions, looking across Glen Dochart southwards, some very large boulders were descried on the N.E. shoulder of Ben More (3843 feet). They were on a little flat, at about from 1750 to 2000 feet up. These could not be "fallen blocks." The ridge on which they rest was too narrow, and the slope too great, for falling masses to have been arrested where they lie. Ice seemed the more probable agency.

On a review of the facts observed during the foregoing excursions, I cannot explain them by the agency of local glaciers; nor can I conceive how a great solid mantle of ice covering the whole country,

and sliding over the hills, could have left the number of blocks we saw on their summits.

4. *Excursion over the hills situated to the east of Loch Laggan, in Lochaber, Inverness-shire.* (IV. *and* V. *were with Rev. Mr Peyton.*)

Started from Loch Laggan Inn, and went N.E. by *Meall Ghrealach* (1650 feet), *Buidh' Aonach* (3037 feet), along the ridge to *Creag Meaghaidh* (3700 feet), thence descending upon Moy.

On the south slope of *Buidh Aonach*, two grey granite boulders were found on a small plat at 2260 feet contour line.

About the centre of the long ridge, and nearly due N. of the centre of Loch Laggan, there is a round and broad eminence 3238 feet high. This eminence is bedded with gravelly clay, resulting apparently from the disintegration of granite belts in the gneiss. We counted on this eminence about twenty-four large and much-rounded grey granite boulders, identical in character with those seen on the south slope of the hill above mentioned. Some of them were lying on the surface of the clay, some were half bedded. Veins of granite were found in the flaggy gneiss of the hill. In these veins there were masses in every stage of being rounded by decay and by weathering, becoming loosened out of the gneiss rock, with portions of the rock adherent. None were so large as the blocks lying in the adjoining district.

It occurred to me that many grey granite blocks considered to be boulders may have originated in this way, and may have been pushed from their birthplace,—as, for example, the blocks seen on the south slope of the hill above referred to.

In last year's Report reference was made to grey granite boulders seen on or near the top of *Craig Dhu* (2161), at the mouth of Glen Roy, about 15 miles west of Buidh Aonach. Might these not have originated in the same way? No veins, however, were seen on Craig Dhu.

5. *District near Loch Clunie, north of Caledonian Canal.*

1. In driving up *Glen Morriston*, we observed at the east end of the summit of a hill about 1000 feet above the sea, near the junction

of the River Loyne with the stream flowing from Loch Clunie, "a *grand* boulder;" but it was some distance from the road along which we were driving, and we could not reach it.

From Clunie Inn we ascended *Carn Ghluasaid* (3140 feet); *Carn Glas* (3260 feet); *Sgùrr nan Conbhairean* ("*Ben-doe*") (3634 feet); *Carn Dubh Liath* (3280 feet); and *Garbh leac* (3673 feet), and then back to Clunie Inn.

On the south slope of the first-named hill, at a height of 1475 feet, we found two grey granite boulders, each about 3 cubic yards in bulk, stopped against a little knoll to the S.E.

3. On another day we climbed *Stob Bathaich* (2740 feet) (opposite *Am Bathaich*), the S.E. spur of *Carn Fuaralach* (3241), and found on it two blocks. At the height of 850 feet, and at a distance of about 400 yards north of Clunie Inn, several fragments of rock were found, which we ultimately considered to be fallen rocks.

At a height of about 1520 feet, on the east slope of the same hill, we found several large blocks, which had been clearly transported. They are angular, and their resting on so steep a slope was most striking. The largest is represented on fig. 11.

On the same hill, at a height of about 2000 feet, and on its S.S.W. slope, we found an angular block $13 \times 5 \times 4$ feet. Observing not far off an outcrop of rock of the same description (white quartzy gneiss), about 7 feet high, and bearing W.N.W., about 65 paces distant, and at a somewhat higher level, we saw such appearances on it as to convince us that the block had somehow been torn off from this rock, and lodged where it now lies, viz., about 15 feet below the level of the rock. Between the block and the outcropping rock there is a gully, or hollow, about 15 feet deep, now occupied by a small stream, across which the block must have been carried,—by what agency is the question (see diagram 11).

3. We next proceeded over the hill tops the whole way north to Achnasheen, and were much interested in the number of cases of boulders lying on very steep slopes of high hills. One of the hills ascended was *Sgurr na Lapaich* (3778 feet). From the spongy nature of the grass it was the hardest climb I ever experienced. For about 1500 feet above *Loch Mullardoch*, the slope was at an angle of 47°. At the height of about 1530 feet (above the sea) there rests on the slope a boulder $12 \times 8\frac{1}{2} \times 7\frac{1}{2}$ feet, of hard quartzy

gneiss. "Did that stone roll down that slope and stick there?" I asked the shepherd who walked with us. The instantaneousness and energy of his "Never!" was delightful. "And why not?" I asked. "Well, in the *first* place, not a peeble can stop on sic a slope, let alane sic a stane as yon, if she ance fetched wey; in the *second* place, there are nae stanes ava on the tap, but jist a peat bog; and in the *third*, there's no a stane just exactly of this natur' in the hill." We found, on surmounting the first heave of the hill, 2250 feet, a wide expanse of bog.

6. *Aberfoil.*

Ascended two small hills. The first (*Arndrum*) is a portion of the ridge of *conglomerate rock* which, in the east, occurs at Callander, and in the west crosses Loch Lomond, forming a line of islands. The ridge thus stretches E.N.E. and W.S.W.

On this hill I found, at the height of 230 feet, a line of six boulders of angular fragmentary gneiss (greywacke), stretching from N. to S. They were closely adjacent, viz., from 2 to 20 feet apart, and from $\frac{3}{4}$ to 3 cubic yards in size.

To the west of this line, four other similar boulders lay along the summit of the ridge, and thus at right angles to the first line. They stretched nearly to the top of the hill, viz., to 454 feet.

III.—*NOTES BY MR MURRAY, GLASGOW.*

Islands of Colonsay and Oronsay.

Mr Murray of No. 169 West George Street, Glasgow, having during the last two summers spent some weeks in the island of Oronsay, was so obliging, at the request of the Convener, as to search for boulders on these islands, and has sent to the Convener notes, from which the following are extracts:—

1. *Oronsay.*

Along the sea-beaches the shingle is found to contain pebbles and blocks of syenite, grey granite, and greenstone.

The syenite may probably have been derived from rocks at Killoran Bay, in Colonsay, about 9 miles distant to the N.N.W.; and

the grey granite and greenstone from rocks at and near Schallasaig, about 5 miles distant, on the east side of Colonsay, to the N.N.E.

There are also fragments of a bright red granite, with large crystals; but no rocks of a similar composition were met with on either island. These were found at "Port na Long," on the west shore of Oronsay, and also at Poll Gorm, on the eastern extremity of Oronsay.

A little to the south of the large sandy bay on the east side of Oronsay (Traigh na Shella), there is a boulder of coarse-grained granite, "of a *pinky* colour," probably the same kind of rock as that found at and near Schallasaig. Its size is 3 × 2 × 2 feet.*

Near this boulder there is one of quartzite, 2 × 2 × 2 feet, differing in composition from any rocks seen. Beside it there are nodules of chocolate red sandstone; also not seen on the island *in situ*.

A little to the south in a narrow gully, there is another coarse quartzite 4 × 3 × 3 feet, partly bedded in the sand.

Highest hills in Oronsay (304 feet) are rounded, and the rocks near the base are generally smooth, like those now washed by the sea. No boulders were seen on them.

The strand, a low sandy tract, dividing Oronsay from Colonsay (covered by the sea at high water), has several boulders of small size on it, and in particular one of red sandstone and one of a reddish-grey granite.

On the west side of the strand, on the farm of *Garbh*, there are several small boulders of grey granite.

2. *Colonsay.*

At Schallasaig (a harbour on the east coast) there is a considerable extent of grey granite rocks *in situ*—and across the island, towards the west, there is a depression or hollow, which reaches to the coast. Strewed over this hollow there are blocks of Schallasaig granite. About half-way across there is a hill about 20 feet high, called "*Cnoc an Ard Righ.*" The Schallasaig granite rocks apparently come no farther west than this hill.

* *Note by Convener.*—Professor Geikie, in a recent paper published in the *Transactions of the Glasgow Geological Society* (vol. vi. p. 160) on the "Geology of Colonsay," mentions, that in the neighbourhood of Schallasaig there is a "granitoid rock" containing *felspar*, "which sometimes shows a rosy flush."

Near Meall Buic, situated about 2 miles S.W. of Schallasaig, a great pit has been opened for gravel and sand. In this pit, a number of boulders occur, the largest about 4 feet long. Two of these have striæ or ruts on their surface, parallel with longer axis. Though many are apparently of Schallasaig granite, there are others, which were not recognised as the same as any rocks on the island.

Some basaltic or whinstone dykes occur on the east coast, a little south of Schallasaig; and boulders of these occur to the west.

At the foot of Dungallon hill (on S.W. coast) there is a sand pit, with a considerable number of boulders, from 1 to 2 feet long, apparently water-rolled. The height above the sea is from 40 to 50 feet.

On the south side of Dungallon, there is Port Loth, where several boulders (about $2 \times 2 \times 1$ feet) of grey granite occur. In a gully in the rocks on N.E. side there is a grey granite boulder, $4 \times 2\frac{1}{2} \times 2\frac{1}{2}$, and one of trap, $4 \times 3 \times 2\frac{1}{2}$ feet, well smoothed. To the north there are more, all apparently the same as Schallasaig; but besides them, there are some granites of a yellowish-red colour, different from any *rocks* seen.

In the N.W. part of Skipness the hills are rounded and smoothed, but no boulders were seen on them.*

3. *Shingle Beaches.*

Along the shores of both islands, and even on inland spots, especially in Colonsay, there are extensive collections of pebbles and small boulders, all evidently water worn,—some of them reaching to a height of 70 feet above the present shore. The pebbles and boulders

* *Note by Convener.*—With reference to the granite boulders, which in most cases Mr Murray seems inclined to connect with the Schallasaig granite rocks, it should be kept in view that at Killoran (in the N.W. of Colonsay) there are, as Mr Murray states, "rocks of both red granite and grey granite, which rise in masses to the height of 200 feet. The grey is found as far east as Ballinahard. At the same place there is an exposure of a third granite, of a dark colour, resembling syenite. In the same neighbourhood the schist is much contorted and burnt; and at its junction with the granite there is a vein of quartz rock or quartzite."

Professor Geikie, in his memoir on the "Geology of Colonsay," already quoted confirms Mr Murray's statement, when he refers to "a crystalline rock which appears to be of igneous origin, a syenite consisting of pink felspar and dark green hornblende. It occurs near Skipness, in the north of Colonsay, in which district, the schistose and gneissose strata are much broken and confused."

consist chiefly of hard crystalline rocks—granite of the grey variety is the most common, but there is also red granite and syenite. One specimen of *flint* was found, much rounded and smooth, as if water worn. The specimen having been sent to the Convener, he forwarded it to Professor Heddle for his opinion. He returned it, stating that it is a "chalcedonic silica," not in the least resembling what occurs in "the Liassic beds of our west coasts," and he suggests that it had probably somehow been transported from Ireland.

The Convener asked whether this flint specimen may not have been brought by a boat or ship? Mr Murray replied that this was impossible, on account of the position where it was found.

Mr Murray gives a list of the various kinds of pebbles and blocks found by him in the raised shingle beach on this part of the coast, and he has sent chips of these with his notes.

In this list the following are mentioned :—

"Red granite, with large flakes of red felspar.

"Claystone porphyry, with imbedded crystals of a chocolate colour.

"White micaceous indurated sandstone.

"Crystalline slate.

"Indurated sandstone ; irony stained.

"Chocolate-coloured claystone.

"Syenite.

"Quartzite.

"Claystone porphyry amygdaloidal; chocolate coloured; large imbedded crystals." *

A little way to the north of Dungallon, the raised shingle beach s extensive. There are three terraces rising from the sea-level, each about 7 feet in height. The uppermost and the one next to it, each forms a horizontal flat, about 10 feet wide. The level of the highest part of the beach is about 80 feet above high-water mark.

The shingle extends as far north as the village of Kilchattan. Traces of an old beach at the height of about 60 or 90 feet above sea-level are visible there.

* *Note by Convener.*—Can this be a pebble derived from the rocks in Killoran Bay, described by Professor Geikie as "a remarkable volcanic agglomerate—made up of the broken angular débris of the strata by which it is surrounded?" (Page 160.)

IV.—*NOTES BY DR TRAILL (ORKNEY).*

Ronaldshay Island (Orkney).

North Ronaldshay.—In the Committee's Report for 1882 Dr Traill stated that the rocks *in situ* consist almost exclusively of Old Red Sandstone flags. On the surface of the island there are several boulders of foreign origin, viz., one of "*coarse conglomerate*," a rock occurring at Heclabir, in the adjacent island of Sanday, situated to the S.W.; smaller blocks of *granite* and *syenite*, transported possibly from Stromness, Pomona Island, distant from Ronaldshay about 45 miles to S.W., between which and Ronaldshay there are several islands and deep-sea sounds; also a stone resembling coarse *jasper*. Some of these blocks have their surfaces flattened and smooth, and in some instances shining, as if they had been ground down and polished.

In a subsequent communication to the Convener, dated 24th Nov. 1882 Dr Traill states, that having recently had to cut a number of trenches or drains through his property near the centre of the island, he had found boulder-clay containing specimens of *flint*, *chalk*, *oolite*, *limestone*, and *sandstone*, and other stones foreign to the island. A portion of one of these stones having been submitted for examination to Dr Heddle, of St Andrews University, he considered it to be a portion of augitic rock, much the same as what he had seen in the island of St Kilda, but nowhere else.

In the North Ronaldshay boulder clay, fragments of marine shells occur, especially *Cyprina Islandica*, and traces also of the more fragile *Astarte* and *Dentalium*.

Professor Heddle writes (16th Dec. 1882) to the Convener regarding these specimens as follows:—"I send to you one of the pieces of flint which Dr Traill got out of the 'till' of N. Ronaldshay, to show how similar it is to the piece of flint you sent to me from Colonsay, which I have no doubt came out of Irish limestone. I never saw chalcedonic silica (as this is) in the least resembling it, in any of the Liassic beds of our West Coast.

"Dr Traill has also shown to me among his spoils from the North Ronaldshay 'till,' two unquestionable pieces of Torridon conglomerate. There is no manner of doubt as to these. He saw many

large pieces of it. These *must* have come from some site between the Kyle of Durness and Loch Carron.

"Again, another piece of rock is not to be distinguished from a mass of granular labradorite, which I found near the summit of one of the hills in Rum Island.

"I have taken some trouble with these specimens, qualitatively analysing about four of them. Though somewhat differing in appearance, they are all coming out a finely crystalline, dense, pale yellow *dolomite,* approaching to marble, and so may have come from Assynt or the north of Ireland.

"It is most marked, the great number of pieces of this one kind of rock. I regard it as a '*find*' of importance; for surely now that it has been analysed, the rock can be found somewhere *in situ.*"

In a memoir on the Orkneys by Messrs Horne and Peach (*Quarterly Journal of London Geological Society* for Nov. 1880), it is mentioned, that in the island of *Stronsa* (not far from Ronaldshay) boulder clay on the eastern shore forms "a continuous cliff for nearly half a mile." "The deposit, which varies from 20 to 30 feet in depth, consists of a tough gritty clay, of a reddish colour, full of well-smoothed and striated stones." "The greater number of included blocks have been derived from the flagstones and sandstone rocks of the neighbourhoods; but the following rocks are likewise represented:—*Granite, pink porphyritic felstone, gneiss, schist, quartzite, white quartz, dark limestone, oolitic breccia, chalk,* and *chalk flints,*—all of which are foreign to the island." (Page 657.)

"Equally important is the presence of numerous *fragments of marine shells* throughout the deposit." "Nearly all the fragments are smoothed and striated, like the stones in boulder clay; there can be little doubt that these characteristics are due to the very same cause in both cases." (Page 657.)

"In the island of *Shapinshay* shelly boulder clay occurs at various localities, and contains finely striated chalk-stones." (Page 657.)

V.—*BOULDERS ON EIGG, AS DESCRIBED IN LETTERS TO THE CONVENER, FROM NORMAN MACPHERSON, ESQ., PROPRIETOR OF THE ISLAND.*

1. *Rocks seen on the Surface.*

1. The S.W. part of the island has on it the remarkable ridge of Pitchstone Porphyry, described by Professor Geikie and others, called *Scoor-Eigg*. The length of the ridge is altogether about two miles. It reaches at its east extremity to a height of about 1300 feet above the sea, at its west extremity to a height of from 900 to 990 feet.

It rises from a plateau, which is about 400 feet above the sea.

Its eastern half runs about E. and W., its western half N.N.W. and N.W.

Both north and south sides are precipitous, almost vertical, showing on the north a cliff 270 feet, and on the south a cliff 400 feet in height.

2. The north part of the island, it is believed, consists of bedded basaltic rock, but, being well covered by grass and moss, the rocks are nowhere visible. The island at its N.E. end rises to a height of about 1080 feet above the sea. At its northernmost extremity it is 990 feet above the sea.

The top of the hill is a smooth plateau, about half a mile broad, from which there is a precipitous dip towards the sea, on the N. and E. It is also precipitous towards a flat basin or hollow on the west, about 180 feet above the sea.

In this basin sandstone and limestone rocks, of the oolitic age make their appearance.

2. *Old* (*apparently*) *Sea-Beaches.*

These occur at two spots, one in the S.E. corner of the island, at a height of about 60 feet above the sea,—the other on the N.W. end of the island, about 100 feet above the sea. They consist of pebbles of rolled gravel, mostly half inch to three inches in length closely compacted.

Except where these beaches occur, there are no gravel beds known on the island.*

* *Note by the Convener.*—In the 6-inch Ordnance Survey map of Rum, two "gravel pits" are indicated as existing in the N.E. part of the island at a height of about 200 feet above the sea.

The soil everywhere consists, apparently, of the débris of volcanic rocks.

But wherever the surface is cut through, as by water courses, small stones of a kind of *granite*, from 6 to 18 inches long, are found.

Most of the walls on the island contain stones of this description gathered off the surface of the land.

Near the Manse there is a wall and also a dam for water, at about 221 feet above the sea, in which there are granite blocks from one to three feet in length.

3. *Boulders.*

1. The largest measured for size rests on the *Scoor* ridge, being 4½ feet long, 4 feet 3 inches broad, and the thickest part 4 feet. It is angular, and may be gneiss. It has a considerable vein of quartz in it.

It is near the western extremity of the ridge, and on a part of the ridge which is lower than any other part, viz., 890 feet above the sea.

It is close to the top of the ridge, on the slope facing the north, and so precariously posed, that the least agitation or concussion by ice, or even water, might be expected to topple it down hundreds of feet.

2. There are other boulders of the same species of granite or gneiss, at heights of from 200 to 700 feet above the sea, on ground sloping from the *Scoor* ridge towards the N.E., and also from the opposite hill down towards a water channel.

In a wall there are numbers of granite blocks of such a size as a strong man can lift.

3. In the N.E. part of the island there is a granite boulder, dark in colour, of a larger size than any other. It is on the part of the hill sloping down towards the S.W., about 600 or 700 feet below the top of the hill, and about 300 feet above the sea. A rock very like that composing this boulder (Mr Macpherson states) he has seen on the shores of Loch Alsh, situated to the east of Skye, about 50 miles north of Eigg.

The boulders (Mr Macpherson states) "are of every variety of gneiss and granite, some very dark, some very white, some red, some with little or no mica, some with a great deal."

Mr Macpherson adds that there are no gneiss or granite rocks in the island; that he has seen rocks of that description in islands and on the mainland, to the N.W., N., and N.E., but that being not sufficiently acquainted with the qualities of these rocks, he cannot venture to indicate the sources of the Eigg boulders.*

* *Note by the Convener.*—The foregoing report on Eigg having been submitted to Professor Heddle, he wrote to the Convener that he had never visited Eigg, but that he was well acquainted with the rocks in Rum, Mull, and Skye. He states that there is no *true* granite in Rum; but that at the S.W. corner of the island there is a large mass of a "variety of syenite, something like grey granite"; and that this syenite, and also the augite rock of the island, are of the "same type as that of the Coolins in Skye, and of St Kilda." He adds that this augite rock is so peculiar, that if the Eigg boulders came from any of the above-mentioned rocks in these islands, he might perhaps be able to recognise them, on getting chips from the boulders.

In consequence of this last remark by Professor Heddle, the Convener applied to Mr Macpherson, to endeavour to obtain chips of the larger boulders in Eigg. In the course of a few weeks about a dozen chips were obtained, and were sent to the Convener.

The Convener thereupon forwarded them to Professor Heddle, who, after a first cursory examination, wrote to the Convener as follows:—"None of the boulders (judging by the chips) are from any point I know. None are granitic. One is a micaceous syenite, with characteristic radiation structure in its felspar. There is a micaceous gneiss—I think a Tiree rock. The others are either highly metamorphosed grits, simulating granites, or gneissose rocks. All are so characteristic that their source is certain to be sooner or later discovered. The island should be visited, to note carefully the features of the '*lie*' of each boulder."

A few days afterwards Professor Heddle wrote to the Convener, that having again examined the chips he found that "they consist of highly metamorphosed grits of gneiss, and of syenite;—they are all of much greater age than any rocks described as occurring in Eigg"; and suggested that they might be submitted to Mr Archibald Geikie and also to Professor Judd, both of whom he knew were well acquainted with West Highland rocks.

The Convener accordingly transmitted the chips to Professor Judd, with a request that if Mr Geikie was in London, he would have the goodness to show them to him.

The Convener has received a note from Professor Judd stating that Mr Geikie and he had looked at the specimens, and he fixes on one which he says "I take for Torridon Sandstone. It is an Arkose, which Mr Geikie thinks may have come from the Torridon group;—but that it reminds him most of some parts of the Old Red Sandstone. None of the boulders are at all like any of the volcanic masses of the Inner Hebrides."

"All the boulders, we both agree, may have come from the great gneiss masses of the central Highlands, and they do not appear to belong to the old Lewisian or Laurentian series. Mr Geikie adds, 'I do not think anybody could venture to fix their source more precisely'; and in this I quite agree with him

Mr Geikie, in his account of the Geology of Eigg, adverts to the channe

VI.—*NOTES ON FLINT NODULES FOUND ON RAISED SEA-BEACHES AND DRIFT GRAVEL IN WIGTOWNSHIRE. BY REV. GEORGE WILSON, COR. MEM. S.A. SCOT.*

Mr Milne Home asks me (January 1883) for an extract on this subject from an article by me (in vol. i. of the *Collections of the Ayrshire and Wigtownshire Archæological Association*), on the Ancient Stone Implements of Wigtownshire, and to give some additional notes. The passage occurs at page 4.

"The Glenluce implements of flint and other kinds of stone, and of bronze, were first described in 1876, in my notes of some of the articles then presented by me to the Museum of Antiquities in Edinburgh (*Proc. Soc. Antiq. Scot.*, vol. xi. pp. 580–587). The Glenluce flints, &c., are chiefly found on or near certain old sea-beaches at the north shore of the Bay of Luce. These are about 20 feet above the sea-level, and run from north-east to south-west, in parallel storm-beaches, from a point near Park Hay, in Glenluce, to a point near Sandhead, in Stoneykirk, a distance of about six miles. These beaches are in most places covered by sand hills, called the Torrs. They contain many *water-worn nodules of flint.* How did these flints get there? In the paper referred to, I hazarded the opinion that they are 'the relics of a (vanished) *Scottish deposit of chalk*:' but geologists demurred to this, and were inclined to think they had been imported as articles of commerce. One correspondent, who is an eminent geologist, thought they had been brought in *coracles* from the north of Ireland, where flint is plentiful. I am now able to state that *they have been deposited by natural agency*, for I have found them in the *stratified gravel*, in a large excavation at Dunragit railway station, and in a gravel pit at Genoch, which is near some of the old beaches where I have found flints, both wrought and unwrought. It is for geologists to discuss whether they have drifted from the north of Ireland

of an ancient river, in which he detected "pieces of *red sandstone* 'of Cambrian derivation'—which make it clear that the higher grounds from which they were borne could not have lain to the S. or E., but *to the N. W. or North.*" From fragments of white sandstone (also found by him), he says, "We may with some probability infer, that the course of the stream (which brought them came from the north, where the great white oolite sandstones rise to the sur face."—*Lond. Geol. Soc.*, vol. xxvii. p. 309.

or some other quarter. For archæologists it is an interesting question whether this deposit of drift contains chipped flints of the palæolithic period. As yet I have found none."

In a paper in the *Proc. Soc. Antiq. Scot.* for 1881, new series, vol. iii. p. 262, I note that these parallel beaches "are also seen in the cultivated fields in the farm of Culmore in Stoneykirk."

The fact that many of the flints are not as large as a pea, led me to think that they were not imported by human agency. After repeated search, I found flints *in situ* in the strata of drift in the gravel pits at Dunragit station at 70 feet level, Genoch at 25, and at other places. This fact explains their presence on the raised beaches and in the bed of streams.

Near Glenluce three successive sea-beaches are marked by three terraces, more or less distinct. The lowest, from 15 to 25 feet above the present sea-level, is well marked in many parts of Wigtownshire, and contains many caves worn in the Lower Silurian rocks. The two higher lines are carried to the north and west of Castle of Park, by sand hills, now cultivated. The second beach is about 60 or 70, and the third about 100 feet above the present sea-level. In the highest the sand is covered by stratified gravel from 3 to 6 feet deep. A fine section is seen in the cutting of the Girvan Railway on West Borland farm. I have found no flints there as yet; but there are pebbles of a soft red sandstone, some of which are larger than I can lift. Such pebbles were sometimes used as whetstones, and for other purposes, by the ancient stone-workers. (A broken valve of a species of astarte was got about three feet below the surface at this section.)

In Kirkmaiden parish I have found *large rolled flints* in the stratified gravel at the sea-beach near Drumore village, and *smaller* ones in two gravel pits near Logan House, about 50 feet above the sea. I got a single flint in the cutting exposed by the road at the side of the lighthouse buildings at the head of the Mull of Galloway, about 200 feet above the sea. They are also to be found in a gravel pit near Lochnaw Castle, about 175 feet above the sea, and at Machar, in Inch, about 75 feet.

The great mass of the stones in our drift beaches and river beds consists of pebbles of grey Silurian sandstone. There are many specimens of granite, chiefly grey. Boulders and pebbles of red

granite are more frequent further west in the Rhinn district. Quartz and quartzite pebbles are not uncommon. Many of those on the sand hills have been used as hammer stones. There are pebbles of various porphyries and other rocks which would repay examination by trained geologists. I believe some of the materials of our drift have come from Arran. Flint is plentiful *in situ* in Armagh. At Glenluce the drift is not found very far from the sea. The sections at higher levels show much boulder clay. As yet I have seen no flint in the boulder clay.

VII.—*NOTES BY REV. PROFESSOR DUNS ON BOULDERS IN THE ISLAND OF MULL.*

The Convener having learnt that Professor Duns, one of the Committee, had resided during a portion of last summer in Mull, wrote to ask him whether he had taken note of any boulders.

The following is extracted from Professor Duns' answer, dated 27th April:—

"I spent two months in Mull last year, limiting my wanderings to the northern part of the island.

"Perhaps the best answer to your kind note is to copy from my diary the only notes I made on boulders.

"June 3, 1882, *Tobermory.*—Walked to *Mishnish* first lake. Struck into the hills at the burn on the north. A boulder of coarse reddish granite, on the pretty steep slope of the east bank. This is the first '*heathen*' I have seen. None were met with on the moor across which I passed yesterday, lying between the new road to Sorn and the Sound of Mull.

"June 7th.—Yesterday's drive from *Tobermory* to *Torloisk*, and to-day's ramble among the hills between the *Sorn* road and the *Sound*, and chiefly those lying above the *Runa-Gal* lighthouse, correct my note under 3rd current. Both on each side of the road to *Torloisk* and among these hills, granite boulders are numerous, but few are large. They range in size from that of a 'fist' to twice that of the 'head.' A few well sunk in the soil show a surface 2 to 3 feet broad. The granite is for the most part a coarse *reddish* one. But there are some fine grained '*greys*.' The largest met with is gneiss. A small *quartzite* specimen occurs in the same area.

All are rounded and smooth. Four lie '*en trainée*' widely apart, the line being N. and S.

"June 22nd.—*Tobermory* to more than 3 miles beyond *Calgary*, that is, about 15 miles. As you approach the west coast of North Mull, along this track, the number of boulders gradually decreases, until, say about *Calgary*, I failed to find any in the parts in which I wandered. The contrast is most striking in this respect, between this track and that between *Tobermory*, south-eastward to *Pennygown*, lying at the seaward opening of *Glen-Forsa*. Has ice, moving from the north-west, begun to drop its entangled boulders near the west coast, and the rate of deposit increase as it passed over the track between *Runa-Gal* and *Mishnish*, between *Mishnish* and the S.E. of *Glen Frisa*, and then through *Glen Aros?* Be this as it may, there is no doubt as to the numerical increase of the boulders in this direction. They are all much worn and rounded, and for the most part comparatively small, though some are large enough to have been utilised as gate-posts.

"July 29.—Ascended *Spyon More*, 2435 feet above sea-level. Wandered in search of boulders, of which there are a good many scattered over the hill and on the heights in the immediate neighbourhood;—all, so far as could be ascertained, *granites*—no granite occurring *in situ* in this part of Mull. Four, widely separated, are lying '*en trainée*.' A line drawn from these across the *Sound of Mull*, and over the *Ardnamurchan* hills, would, if extended, pass between *Eigg* and *Rum*. One of them lies on the *very top* of *Spyon More*;—another is met with half-way down the hill. The others lie in the plain out of which the hill rises. The rocks at the summit are well glaciated, and a great heap of moraine-like débris rests on it. Brought away chips from these boulders."

3. On a new Entozoon (*Pentastomum protelis*) from the Mesentery of *Proteles cristatus*, Sparrmann. By W. E. Hoyle, M.A. (Oxon), F.R.S.E., Naturalist to the "Challenger" Expedition Commission.

(*Abstract.*)

The entozoon, which is a new species of *Pentastomum*, was found by Professor Morrison Watson in a male *Proteles cristatus* which had died in the Zoological Society's Gardens.

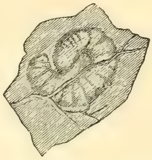


Fig. 1. General appearance of the encysted parasite.

The parasites, to the number of about ten, were found enclosed in cysts in the mesentery, and presented the appearance shown in fig. 1. In every instance except one, the ventral surface of the animal formed the convexity of the curve.

The species may be characterised as follows:—

Pentastomum protelis, n. sp.

Body, cylindrical in the anterior half, slightly tapering posteriorly, terminal segment obtusely pointed. No clear distinction between cephalothorax and abdomen. Head hemispheroidal, equal in diameter to the body. Mouth furnished with a papilla, perhaps a protrusible proboscis. Stigmata arranged in numerous irregular rows on all the segments. Male, 13–17 *mm. in length, with* 16 *or* 17 *annuli. Female,* 20–25 *mm. in length, with* 18–22 *annuli. Habitat, the mesentery of* Proteles cristatus, *enclosed in a connective tissue cyst.*

The above description being taken from specimens which, from their encysted condition, were presumably immature, must be regarded, to a certain extent, as provisional.

The appearance of the ventral surface of the head is shown in fig. 2. In one or two examples the posterior terminal segment aptly fulfilled the expression used by Diesing in describing another species, "cute externâ in formâ præputii," but this was by no means constant.

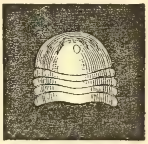


Fig. 2. Ventral surface of the head.

The species bears a close resemblance to *P. polyzonum*, Harley, but is distinguished from it by the number of segments, which, in the case of *P. polyzonum*,

is stated to be constantly nineteen in fully developed females,* and it is very unlikely that an immature form should have more, though it might have fewer, segments than the adult.

With respect to the anatomy of the animal, the following points resulting from this investigation seem to be most worthy of notice.

The *cuticle* is perforated by the usual stigmata, which are seen in section to be somewhat of an hour-glass shape, and immediately internal to each is situated a spheroidal cell or group of very small cells (fig. 3, *d*), with a blunt process projecting into the stigma, the arrangement very forcibly suggesting that the function of this aperture is to evacuate a substance secreted by the cells.

The sub-cuticular epidermis (fig. 3, *b*) consists of columnar nucleated cells, and in many cases processes can be traced passing from these inwards and becoming connected either with the muscle fibres or with the cells forming the parenchyma of the body wall.

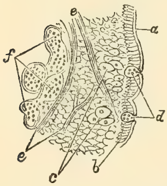


Fig. 3. Transverse section of a portion of the body wall: *a*, cuticle; *b*, layer of epithelium; *c*, large glandular cells; *d*, large cells just within the stigmata; *e*, transverse muscular fibres; *f*, longitudinal fibres.

The *mouth* is annular in form and surrounds a small oval papilla, which is probably capable of protrusion and retraction, seeing that it it is provided with a sphincter muscle, with other muscles placed longitudinally with respect to the body, and with a third group passing inwards at right angles to these.

The *œsophagus* commences at the posterior side of this papilla, and passes inwards and backwards with a double curve, finally entering the stomach some distance behind its anterior margin. At first its section is crescentic, with the horns directed dorsally. It then becomes oval, and still later crescentic again, but with the horns directed ventrally. All this portion of the tube is lined with chitin continued from the external covering of the body. The middle portion of the œsophagus is once more oval in section, and has a well-developed coat of muscular fibres. On passing through the nerve-ring its lumen becomes stellate in section, and it enters a mass of rather large round parenchymatous cells, whose appearance suggests that they are secretory in function, though as yet no excre-

* Bell, *Ann. Mag. Nat. Hist.*, ser. 5, vol. vi. p. 176.

tory passage has been noticed. Possibly they lead by very minute openings into the œsophagus itself, and perform the function of a salivary gland.

The *intestine* or *stomach*, for the alimentary canal presents no division into these two parts, has a straight antero-posterior course, and terminates by a narrow rectum at the hinder extremity of the body. Two mesenteries, not diametrically opposite to each other, but separated by an angle of 90° to 120°, pass from the body wall to the intestine, enclosing also two large glandular bodies ("Hakendrüsen" of Leuckart) which lie one on either side of it.

The *testis* is a long thin-walled dorsally-situated sac, as described by previous observers. Towards its anterior extremity the lower wall presents a thickening in which two grooves are formed, whose walls arch over, and convert them into two tubes, the vasa deferentia, which subsequently become united, and then separate again.

Their course is now round the intestine, one on each side, passing through the "Hakendrüsen," until they reach the ventral aspect of the body, where each becomes connected with the excretory apparatus of its own side.

The *genital apertures* lie side by side a short distance behind the mouth, and each leads into an oval sac, to all appearance the homologue of that which contains the cirrus in *P. tænioides*, except that in the specimens examined it was quite empty.

From the dorso-lateral side of this sac, on which aspect its wall is very much thickened, two tubes are given off, one anterior and one posterior. The anterior tube enlarges, soon after its commencement, to form a small spheroidal chamber, and, subsequently contracting, passes backwards, extends some distance behind the sac, and terminates blindly after a course of three or four millimetres; the end of it is variously coiled.

A little anterior to the middle of this tube the vas deferens comes into contact with it, the walls of the two fusing, but the lumen of the vas deferens is not continued beyond this point; *it terminates blindly.*

The truth of this observation, so exactly opposed to what might have been expected, has been confirmed by the preparation of a very careful series of transverse sections, which show the one tube lined with a perfectly smooth layer of epithelium, passing by

the other, utterly ignoring, if the expression may be allowed, its proximity, while the vas deferens fades away in a mass of rather loose cells without showing the least desire to unite with its companion.

According to Leuckart's account of the development of these organs in *P. tœnioides*, there is first formed a continuous tube extending from the testis to the external surface, and the curved cæcal tube is formed later as an outgrowth from it;* this makes it more difficult to understand why a stoppage should occur in a tube which was once open, and which must be open again in the adult condition of the animal, in order to allow of the functional activity of the reproductive organs.

The posterior of the two tubes given off from the sac above mentioned does not extend backwards beyond the sac itself; its lumen is almost filled, and reduced to a crescentic form by a cylindrical body, attached by one side to the interior of the tube; anteriorly it terminates in a sharp point, and is clearly homologous with two conical bodies which Leuckart has described in *P. tœnioides* under the name "Chitinzapfen,"† and which he regards as being in some way accessory to the process of reproduction.

BUSINESS.

The following Candidates were balloted for and declared duly elected Fellows of the Society:—Mr J. B. Readman; Mr Henry Newcombe, F.R.C.S.E.; Mr Charles Watson.

Monday, 18th June.

PROFESSOR DOUGLAS MACLAGAN, Vice-President, in the Chair.

The Chairman read a Memoir of the late Sir Wyville Thomson, drawn up by Professor Redfern.

The following Communications were read:—

* Leuckart, *Bau u. Entwickelungsgesch. d. Pentastomen*, 1860; S. 134, tab. iv. fig. .

† *Loc. cit.*, S. 78.

1. Bright Clouds on a Dark Night Sky. By the Astronomer-Royal for Scotland.

2. Mathematical Note. By Mr A H. Anglin.

3. Note on the Compressibility of Water, Sea-Water, and Alcohol, at High Pressures. By Professor Tait.

The apparatus employed was of a very simple character, similar to that which was used last autumn in the "Triton."

It consisted of a narrow and a wide glass tube, forming as it were the stem and bulb of a large air thermometer. The stem was made of the most uniform tube which could be procured, and was very accurately gauged; and the weight of the content of the bulb in mercury was determined. Thus the fraction of the whole content, corresponding to that of one millimetre of the tube, was found.

This apparatus had the interior of the narrow tube very carefully silvered; and while the whole, filled with the liquid to be examined, was at the temperature of the water in the compression apparatus, the open end was inserted into a small vessel containing clean mercury. Four instruments of this kind were used, all made of the same kind of glass.

The following are the calculated apparent average changes of volume per ton weight of pressure per square inch (*i.e.*, about 150 atmospheres):—

Fresh Water, at 12° C.

Pressure.	1	2	3	4	Mean.
1	0·00670	*	665	666	0·00667
2	0·00657	*	646	656	0·00653
2·5	0·00651	650	640	648	0·00647
3	0·00641	633	636	636	0·00636

Note.—The first two experiments with No. 2 failed in consequence of a defect in the silvering.

The compressibility of the glass was not directly determined. It may be taken as approximately 0·000386 per ton weight per square inch.

From these data, which are fairly consistent with one another, we find the following value of the *true* compressibility of water per ton, the unit for pressure (p) being 1 ton-weight per square inch, and the temperature 12° C.,

$$0{\cdot}0072\ (1 - 0{\cdot}034\ p)\ ;$$

showing a steady falling off from Hooke's law.

Sea-Water, at 12° C.

Pressure.	1	2	3	4	Mean.
1	0·00606	611	615	627	0·00615
2	0·00595	607	598	601	0·00600
2·5	0·00600	600	594	590	0·00594
3	0·00588	593	586	586	0·00588

Note.—The sea-water employed was collected about 1½ miles off the coast at Portobello.

These give, with the same correction for glass as before, the expression

$$0{\cdot}00666\ (1 - 0{\cdot}034\ p).$$

Hence the relative compressibilities of sea and fresh water are about

$$0{\cdot}925\ :$$

while the rate of diminution by increase of pressure is sensibly the same (3½ per cent. per ton weight per square inch) for both.

With the same apparatus I examined alcohol, of sp. gr. 0·83 at 20° C.

Alcohol, at 12° C.

Pressure.	1	2	3	4	Mean.
1	0·01202	1193	*	*	0·01200
2·5	0·01040	1052	1050	1056	0·01049
3	0·01043	1050	1043	1058	0·01048

These experiments were not so satisfactory as those with water. There are peculiar difficulties with the silver film. I therefore make no definite conclusion till I have an opportunity of repeating them.

I intend to perform the whole of these experiments at other temperatures, with the identical apparatus, as soon as possible next winter.

Monday, 2nd July 1883.

Mr ROBERT GRAY, Vice-President, in the Chair.

The following Communications were read :—

1. Note on the little *b* group of lines in the Solar Spectrum, and the new College Spectroscope. By the Astronomer-Royal for Scotland.

2. On Superposed Magnetisms in Iron and Nickel. By Professor C. G. Knott, D.Sc.

(*Abstract.*)

When an iron wire is magnetised longitudinally, it lengthens in the direction of magnetisation, according to an old discovery of Joule's. More recently Wiedemann showed that when wire is at the same time magnetised circularly it tends to twist. Thus, if an iron wire be fixed at one end, and stretched vertically by means of a mass attached to the free end, the free end will twist round when the wire is both traversed by one current and magnetised by another which traverses a helix surrounding it. If the wire is magnetised so as to have the north pole down, a down current will make the free end twist in the direction of the hands of a watch as looked at from above. Reversal of either current reverses the direction of twist; reversal of both produces no alteration. Maxwell and Chrystal have pointed out that Wiedemann's phenomenon can be explained by means of Joule's.

In the experiences that form the subject of the paper this was verified, and other peculiarities in the twisting of iron under the influence of these magnetisations were discovered which tend more securely to establish this relation. Thus, when the linear current (the current along the wire) was kept constant, the twist reached a maximum for an intermediate value of the helical current, this critical value being greater for a greater linear current—a result in remarkable harmony with the details of Joule's discovery.

Again, for different tensions, the twisting under the influence of two given magnetisations varied, being (with one or two exceptions)

greater for the smaller tension—precisely as Joule's results would lead one to expect. This effect of tension seems to have escaped the notice of Wiedemann, but it was undoubted.

In the case of nickel, the direction of the twist was different from that for iron, a conclusion which Barrett's discovery of the *contraction* of nickel under magnetisation rendered not unexpected. No maximum twist was reached for an intermediate current. Otherwise the results were the same as for iron, as, for example, in the case of the tensions.

The experiments were tried with different thicknesses of wire, and all gave the same conclusions.

3. Further Note on the Maximum Density Point of Water. By Professor Tait.

During my long investigations of the "Pressure-Errors of the 'Challenger' Thermometers," but more especially two years ago (*Proceedings*, May 1881), I was led to suspect a lowering of the maximum density point of water by pressure. For I found that the change of temperature of water increased *faster* than in direct proportion to the sudden change of pressure which produced it. These experiments were, at my request, more fully carried out by Messrs Marshall, Smith, and Omond (*Proceedings*, July 1882). Their result was (approximately) a lowering of the maximum density point by 5° C. for 1 ton-weight of pressure per square inch (roughly speaking, about 150 atmospheres). In a note appended to their paper I deduced from their experimental data a lowering of 3°·6 C., and from my own a lowering of about 3° C. for the same pressure.

In November last, when reducing the observations made in the "Triton" (*ante*, p. 45), I found that water becomes more compressible as its temperature is lowered, at least down to 3° C.; and this I regarded as another indirect proof of the lowering of the maximum density point by pressure.

I then determined to try a direct process analogous to that of Hope, for the purpose of ascertaining the maximum density point at different pressures. The experiments presented great difficulties, because (for Hope's method) the vessel containing the water must have a considerable cross section; and thus I could not use my

smaller compression apparatus, which was constructed expressly to admit of measurements of temperature by thermo-electric processes. I had therefore to work with the huge Fraser gun employed for the "Challenger" work, and to use the protected thermometers (which are very sluggish) for the measurement of temperatures. It was also necessary to work with the gun at the temperature of the air,—it would be almost impossible to keep it steadily at a much lower temperature,—so that I had to work in water at about 12° C.

The process employed was very simple. A tall cylindrical jar full of water had two "Challenger" thermometers (stripped of their vulcanite mounting) at the bottom, and was more than half-filled with fragments of table-ice floating on the water, and confined by wire-gauze at the top. This was lowered into the water of the gun, and pressure was applied.

It is evident that *if there were no conduction of heat* through the walls of the cylinder, and if the ice lasted long enough under the steadily maintained pressure, the thermometers would ultimately show, by their recording minimum indices, the maximum density point corresponding to the pressure employed:—always provided that that temperature is not lower than the melting point of ice at the given pressure.

Unfortunately, all the more suitable bad conductors of heat are either bodies like wood (which is crushed out of shape at once under the pressures employed) or like tallow, &c. (which become notably raised in temperature by compression). I was therefore obliged to use glass. The experiments were made on successive days, three each day, with three different cylindrical jars. These had all the same height and the same internal diameter. The first was of tinned iron; the second of glass about $\frac{1}{6}$ inch thick; the third, of glass nearly an inch thick, was procured specially for this work.

With the external temperature 12°·2 C., the following were the results of $1\frac{1}{2}$ tons pressure per square inch, continued in each case for 20 minutes (some unmelted ice remaining on each occasion). The indications are those of two different "Challenger" thermometers, corrected for index-error by direct comparison with a Kew standard:—

Tin Cylinder.	Thin Glass.	Thick Glass.
4° C.	2°·67	0°·83
4°	2°·61	0°·83

The coincidence of the first numbers with the ordinary maximum density point of water is, of course, mere chance. When no pressure was applied, but everything else was the same, the result was

Tin.	Thin.	Thick.
5°·7 C.	5°	4°

It is clear that the former set of numbers points to a temperature of maximum density, somewhere about 0° C., under $1\frac{1}{2}$ tons pressure per square inch. But still the mode of working is very imperfect.

I then thought of trying a *double* cylindrical jar, the thin one above-mentioned being enclosed in a larger one which surrounded it all round, and below, at a distance of about $\frac{3}{4}$ inch. Both vessels were filled with water, with broken ice floating on it, and had "Challenger" thermometers at the bottom. By this arrangement I hoped to get over the difficulty due to the temperature of the gun, by having the inner vessel enclosed in water which would be lowered in temperature to about 3° C. by the application of pressure. The device proved quite successful. The result of $1\frac{1}{2}$ tons pressure per square inch maintained for 20 minutes, some ice being still left in each vessel, was from a number of closely concordant trials—

Temperature in outer vessel, . .	1°·7 C.
Temperature in inner vessel, . .	0°·3 C.

The direct pressure correction for the thermometers is only about $-0°{\cdot}1$ C., and has therefore been neglected.

The close agreement of this result with that obtained (under similar pressure conditions) in the thick glass vessel leaves no doubt that the lowering of the maximum density point is somewhat under 4° C. for $1\frac{1}{2}$ tons, or 2°·7 C. for 1 ton, per square inch. It is curious how closely this agrees with the result of my indirect experiments.

The fact, that an increasing compressibility of water at lower temperatures points to a lowering of the maximum density point by pressure, is easily seen from the consideration of the *surface* which represents the density of water in terms of pressure and temperature as independent variables. Let temperatures in degrees C. be

measured on x, pressures in atmospheres on y, and density on z. Then the section by the plane $y=1$ is a curve with a maximum at $x=4$. But from this section the surface rises, in the direction of y positive, faster for lower values of x (*i.e.*, $\frac{dz}{dy}$ for $y=1$ becomes greater as x diminishes). Hence it is clear that a proximate section, say for $y=2$, has its maximum ordinate for a value of x *less* than 4° C.

In fact, if e be the expansibility of water, it can be expressed as a function of the temperature and pressure alone, *i.e.*,

$$e=f(t, p) .$$

Hence simultaneous changes of temperature and pressure, which leave the expansibility unaltered, are connected by the relation

$$\left(\frac{de}{dt}\right)\delta t + \left(\frac{de}{dp}\right)\delta p = 0 .$$

The maximum density point is a particular case of this, for there the expansibility is zero.

Now, if v be the volume, we have

$$e=\frac{d}{dt}(\log v) ,$$

so that

$$\left(\frac{de}{dp}\right)=\frac{d^2}{dpdt}(\log v)=\frac{d}{dt}\left(\frac{d}{dp}(\log v)\right) .$$

But $-\frac{d}{dp}(\log v)$ is the compressibility, and diminishes with increase of t. Thus $\frac{de}{dp}$ is essentially positive. But so is $\frac{de}{dt}$ so long as the temperature is above the maximum density point. Thus δp and δt in the above equation *have opposite signs.*

I have learned quite recently, and by mere accident, that the lowering of the maximum density point of water has been already pointed out as a theoretical result by processes essentially the same as that just given; first by Puschl* in 1875, then by Van der Waals† in 1876. Both authors refer to experiments made by Grassi‡ for Regnault in 1848, on the compressibility of water

* *Kais. Ac. d. Wiss. Sitzb.*, lxxii. 283.

† *Archives Néerl.*, xii. 457.

‡ *Annales de Chimie et de Physique*, ser. iii. t. 31, 1851.

at different temperatures. Grassi's results were all obtained for pressures of some 10 atmospheres or so at the utmost; and, if they may be trusted, indicate a most extraordinary relation between the compressibility and the temperature of water within a few degrees of 4° C. It seems almost hopeless to attempt to obtain an approximate value of $\frac{de}{dp}$ at 4° C. from Grassi's table. Yet this has been attempted by both of the authors above named.

Puschl calculates that 87·6 atmospheres lower the maximum density point by 1° C. Thus he (virtually) gives the effect of 1 ton per square inch as 1°·7 C. instead of 2°·7 C. as above. Van der Waals gives a much more rapid descent, *i.e.*, from 4°·08 C. at 1 atmosphere to 3°·4 C. at 10·5 atmospheres. He also gives the results of some experiments with the ordinary piezometer, and therefore at very moderate pressures, which indicate a lowering of the maximum density point, but do not lead to definite numerical results.

In order to clear up the whole subject, I intend to repeat all these experiments next winter, when the gun and its contents are naturally at a temperature of about 4° C.

4. On Surface Emissivity. By Professor Tait.

BUSINESS.

Professor Tait laid before the Society a photograph of the arm of a child struck by lightning, sent by direction of Mr Milne Home.

Dr J. Graham was balloted for and declared a duly elected Fellow of the Society.

Monday, 16th July 1883.

THE RIGHT HON. LORD MONCREIFF, President, in the Chair.

The Chairman read a Communication from the Science and Art Department; and an Obituary Notice of the late Mr T. W. Rumble.

The following Communications were read:—

1. On a proposed Edinburgh Marine Station for Biological Research, at Granton Quarry. By Mr John Murray.

2. On Work done on board H.M.S. "Triton" in the Faroe Channel during the Summer of 1882. By Mr John Murray.

3. On the *Pennatulida* dredged in the Faroe Channel during the Cruise of H.M.S. "Triton" in August 1882. By Professor A. M. Marshall. Communicated by Mr John Murray.

4. On the *Asteroidea* dredged in the Faroe Channel during the Cruise of H.M.S. "Triton" in August 1882. By Mr W. Percy Sladen, F.L.S., F.G.S. Communicated by Mr John Murray.

5. On the *Pycnogonida* dredged in the Faroe Channel during the Cruise of H.M.S. "Triton" in August 1882. By Dr P. P. C. Hoek. Communicated by Mr John Murray.

6. On the *Crustacea* dredged in the Faroe Channel during the Cruise of H.M.S. "Triton" in August 1882. By Rev. A. M. Norman, D.C.L. Communicated by Mr John Murray.

7. On the *Tunicata* dredged in the Faroe Channel during the Cruise of H.M.S. "Triton" in August 1882. By Professor W. A. Herdman.

8. On the Proofs of Proportionality of Emissive and Absorptive Power. By Professor Tait.

9. A Contribution to the Chemistry of Nitroglycerine. By Matthew Hay, M.D., Assistant to the Professor of Materia Medica in the University of Edinburgh. Communicated by Professor Crum Brown.

(A full report of this paper appears in the *Transactions* of the Society.)

On account of the identity of the physiological action of nitroglycerine with that of simple alkaline nitrites, it occurred to the

author either that nitroglycerine was not a nitrate of glyceryl as commonly represented, but contained nitrous acid in its constitution, or that it was readily decomposed in the body with the formation of nitrous acid. This suggestion led to an extended investigation of the constitution of nitroglycerine and of the decomposing action of various substances on nitroglycerine. The conclusion arrived at as to the constitution of nitroglycerine was confirmatory of the common belief that it is a tri-nitrate of glyceryl. For it was found that although nitroglycerine yielded a large quantity of nitrous acid when decomposed by alkalies, yet nitroglycerine could not be obtained by acting on glycerine with nitrous anhydride gas, nor did the presence of urea prevent its formation when it was prepared in the usual way by allowing nitric and sulphuric acids to act on glycerine. The yield of nitroglycerine from a given weight of glycerine also closely agreed with its being a tri-nitrate, and was considerably in excess of the yield obtainable had nitrous acid entered into its constitution. An analysis of the elementary composition of nitroglycerine, which was carried out in conjunction with Mr Masson,* also led to the same opinion.

With respect to the decomposing action of various substances on nitroglycerine, the novel and interesting result was obtained that potash, soda, ammonia, or an alkaline carbonate decomposed nitroglycerine, when heated with it for a longer or shorter period, forming an amount of nitrous acid corresponding almost precisely to the reduction of two-thirds of the nitric acid which nitroglycerine contains. It was also found that the proportion of alkali necessary for this decomposition was 5 molecules of the alkali to 3 molecules of nitroglycerine, and, therefore, a much larger proportion of alkali than has hitherto been believed to be necessary. Further, in direct contradiction of all previous statements, no glycerine could be discovered amongst the products of decomposition, which, besides nitrite of the alkali, consisted of nitrate, acetate, formate, and oxalate of the alkali, a reddish aldehydic resin, and a body capable of gelatinising in alcohol. The amount of nitrous acid was not affected whether alcohol or water was used as the medium in which the alkali was allowed to act on the nitroglycerine.

A solution of phosphate of soda (Na_2HPO4) acted on nitro-

* *Vide* following paper.

glycerine in almost the same manner as an alkali, only much less powerfully. Chloride of sodium had extremely little action. Strong solutions of mineral acids, as hydrochloric and sulphuric acids, acted much more slowly than alkalies, and, as was to be expected, only a trace of nitrous acid was found amongst the products of decomposition. Contrary to the experience of De Vrij, sulphuretted hydrogen was found to have no action on nitroglycerine when dissolved either in ether or in alcohol. Alkaline sulphides, on the other hand, acted very energetically on nitroglycerine, and decomposed it even more powerfully than alkalies. The stronger action of the sulphides was especially noticeable when a watery and not an alcoholic solution was allowed to act on the nitroglycerine. Under this condition an alkali decomposes nitroglycerine very slowly, and only after heating for several hours; an alkaline sulphide decomposes it in almost as many minutes.

Nitroglycerine heated for one hour with alcohol alone did not exhibit any signs of decomposition; heated with water for three hours it decomposed slowly.

Some experiments were made to ascertain the highest possible practical yield of nitroglycerine from a given quantity of glycerine, and the best proportion of acids to obtain this yield. The highest yield was over 95 per cent. of the theoretical yield, and this was obtained by adding 1 part of glycerine to 9 parts of an acid mixture, consisting of 2 parts of strong sulphuric acid to 1 part of fuming nitric acid. The yield was not improved by substituting fuming sulphuric acid for the ordinary strong acid; and the yield was greatly lessened when ordinary strong nitric acid was substituted for fuming nitric acid. The yield was not to any considerable extent increased by allowing the acids to remain in contact with the glycerine for a longer period than five minutes. By whatever method, or with whatever proportion of acids the nitroglycerine was prepared, the products were all found to be uniform in their physical and chemical characters. Nitroglycerine does not therefore appear to be a body of variable composition as some chemists assert (Hess). It is always perfectly colourless, and not yellowish as is sometimes stated. The yellow colour is probably for the most part due to the nitroglycerine having been washed in the process of its manufacture with a solution of soda, which decomposes it.

Its solubilities were carefully ascertained, and it was found to be very slightly soluble in water; largely soluble in ethylic alcohol, but much more soluble in methylic alcohol or methylated spirit; and soluble in every proportion in ether, chloroform, glacial acetic acid, and carbolic acid; freely soluble in benzol; difficultly soluble in carbon disulphide; and practically insoluble in glycerine.

On account of the constancy observed in the amount of nitrous acid produced when nitroglycerine is decomposed by an alkali, the author suggests a method for estimating nitroglycerine by decomposing it with potash or soda in alcoholic solution, and afterwards determining the amount of nitrous acid by means of starch and an iodide.

10. The Elementary Composition of Nitroglycerine. By Matthew Hay, M.D., and Orme Masson, M.A., B.Sc. Communicated by Professor Crum Brown.

(A full report of this paper appears in the *Transactions* of the Society.)

Investigations have been made by Railton, Williamson, Hess and Schwab, Beckerhinn, and Sauer and Ador for the purpose of ascertaining the elementary composition and the constitution of nitroglycerine. They all agree in regarding it as a nitrate of glyceryl; but, whilst some consider that it is a tri-nitrate, others hold that it is a variable mixture of the tri-nitrate with di-nitrate and mono-nitrate. Their analyses are quite insufficient to establish either the one or the other conclusion, and have mainly been confined to estimations of the nitrogen. If we except a comparative estimation of the carbon with the nitrogen, there exist absolutely no determinations of the carbon or of the hydrogen. And, as the decomposition of nitroglycerine with potash has been shown to occur in a manner considerably different from that suggested by Railton and Williamson, the main reason in support of the constitution of nitroglycerine as a tri-nitrate has been removed.* The authors of the present communication therefore believed that they were amply justified in making a fresh and more careful and complete analysis of the composition of nitroglycerine. Absolute determinations were made, not only of the nitrogen, but also of the carbon and

* *Vide* preceding paper by Matthew Hay.

hydrogen; and, in order to ascertain the uniformity in composition of nitroglycerine, the nitrogen of samples prepared by various methods was estimated. The nitroglycerine was both pure and thoroughly dried. For the determination of the nitrogen, modifications of Dumas's method and of Schloesing's method were employed. The carbon and hydrogen were estimated by a modification of Liebig's method. Every precaution was taken to insure that the results obtained should be correct. The average of the determinations gave 15·91 per cent. of carbon, 2·49 per cent. of hydrogen, and 18·05 per cent. (Dumas) or 18·14 per cent. (Schloesing) of nitrogen. Theoretically nitroglycerine, regarded as the tri-nitrate of glyceryl, contains 15·86 per cent. of carbon, 2·20 per cent. of hydrogen, and 18·50 per cent. of nitrogen. The quantities obtained by experiment agree so closely with the theoretical quantities that they may be regarded as affording proof that nitroglycerine is, in reality, the tri-nitrate of glyceryl. The authors also conclude, from the unvarying amount of nitrogen obtainable from variously prepared specimens of nitroglycerine, including one from Nobel's dynamite, that nitroglycerine is constant in composition and does not contain any of the lower nitrates of glyceryl, unless very imperfectly washed.

BUSINESS.

The President, at the close of the meeting, gave a brief review of the Session. He said there had been four Papers on Astronomy, two on Botany, seven on Chemistry, two on Geology, four on Mathematical subjects, six on Meteorology, twenty-three on Natural Philosophy, nine on Natural History, three on Philology, two on Political Economy, and one on Physiology—sixty-three papers in all, independently of the Obituary Notices which had been read. He thought he was not wrong in saying these papers had combined an amount of interest, ability, and novelty which could hardly be excelled, and to a very large extent showing great progress in the subjects treated. He congratulated the Society on having reached the point at which they now stood that night. The Session, he believed, had been a very successful and a very interesting one, and the topics treated of had been of the greatest possible importance. He said, in opening the Session, that it was the 100th Session

of the Royal Society, and he thought he used a certain amount of artifice or subterfuge when he made that representation. They had now concluded the 99th Session, and not the 100th. Like other centenarians, their claims up to this point had not been well-founded, as the first year of the century began in November 1783. At that time the Society was divided into two Classes—the Physical and the Literary. The Physical met first on the 4th of November 1783, and the Literary on the 17th of the same month. They would, however, celebrate the commencement of their 100th Session on the first Monday in December. Referring to the division which originally existed in the Society as to Physical and Literary classes, the President said that some one had suggested that they should follow in the footsteps of their predecessors, and have at intervals purely literary papers read in the Society. The reason why that for a Society of that kind scientific researches were more appropriate was that the literary was fluctuating and stationary, whereas the scientific papers read at their meetings marked the progress of science. Still, he had an ambition in some degree or other to resuscitate that good example of their forefathers, and accordingly next Session he would invite any of the Fellows of the Society who felt inclined to form a Literary class. In conclusion, the President said that at the commencement of next Session he would review the hundred years' history of their Society.

The following Paper was read June 18th:—

Mathematical Note. By A. H. Hallam Anglin, M.A., LL.B., M.R.I.A.

If

$$x^m = p_1 x^{m-1} + p_2 x^{m-2} + p_3 x^{m-} + \ldots + p_m \quad . \quad . \quad \text{(A.)}$$

then will

$$x^n (n > m) = P_1 x^{m-1} + P_2 x^{m-2} + P_3 x^{m-3} + \ldots + P_m ,$$

where

$$P_r \equiv p_r \cdot h_{n-m} + p_{r+1} \cdot h_{n-m-1} + p_{r+2} \cdot h_{n-m-2} + \ldots + p_m \cdot h_{n-2m+r} ,$$

h_n *being the sum of the homogeneous products of the roots of* (A) *of* n *dimensions.*

1. In order to establish this proposition it will be necessary to premise the following lemma :—

If $a_1, a_2, a_3, \ldots a_m$ be roots of the equation

$$x^m = p_1x^{m-1} + px_2^{m-2} + p_3x^{m-3} + \ldots + p_m \,,$$

then

$$h_n(n > m) = p_1 \, . \, h_{n-1} + p_2 \, . \, h_{n-2} + p_3 \, . \, h_{n-3} + \ldots + p_m \, . \, h_{n-m} \,,$$

where h_n is the sum of the homogeneous products of $a_1, a_2, a_3, \ldots a_m$ of n dimensions.

The proof of this may be briefly indicated thus :—We have

$$x^m - p_1x^{m-1} - p_2x^{m-2} - p_3x^{m-3} - \ldots - p_m$$
$$= (x - a_1)\,(x - a_2)\,(x - a_3) \ldots (x - a_m) \,.$$

Writing $\frac{1}{x}$ for x and multiplying off by x^m we get

$$\frac{1}{1 - p_1x - p_2x^2 - p_3x^3 - \ldots - p_mx^m}$$

$$= \frac{1}{1 - a_1x} \cdot \frac{1}{1 - a_2x} \cdot \frac{1}{1 - a_3x} \cdots \frac{1}{1 - a_mx} \,.$$

Thus

$$(1 + \ldots + h_{n-m} \, . \, x^{n-m} + \ldots + h_{n-3} \, . \, x^{n-3} + h_{n-2} \, . \, x^{n-2} + h_{n-1} \, . \, x^{n-1}$$
$$+ h_n \, . \, x^n + \ldots)\,(1 - p_1x - p_2x^2 - p_3x^3 - \ldots - p_m \, . \, x^m) = 1 \,;$$

hence, since this is an identical equation, equating to zero the coefficient of x^n in the first member, we get

$$h_n - p_1 \, . \, h_{n-1} - p_2 \, . \, h_{n-2} - p_3 \, . \, h_{n-3} - \ldots - p_m \, . \, h_{n-m} = 0 \,,$$

or,

$$h_n = p_1 \, . \, h_{n-1} + p_2 \, . \, h_{n-2} + p_3 \, . \, h_{n-3} + \ldots + p_m \, . \, h_{n-m} \,.$$

2. We can now establish our proposition—to express $x^n(n > m)$ in the manner indicated above.

For greater clearness we shall first consider a particular case—

$$x^4 = px^3 + qx^2 + rx + s \,.$$

Multiplying both sides of this equation by x, writing for x^4 its equivalent value, and arranging, we get

$$x^5 = (p^2 + q)x^3 + (pq + r)x^2 + (pr + s)x + ps ;$$

but by the lemma

$$h_n = ph_{n-1} + qh_{n-2} + rh_{n-3} + sh_{n-4} ,$$

and in particular $h_1 = p$, $h_2 = ph_1 + q$, $h_3 = ph_2 + qh_1 + r$, &c., where h_n is the sum of the homogeneous products of the roots of $x^4 = px^3 + qx^2 + rx + s$ of n dimensions. Thus

$$x^5 = h_2 \,.\, x^3 + (qh_1 + r)x^2 + (rh_1 + s)x + sh_1 \,.$$

Repeating the above process on this equation we shall find, on again applying the lemma, that

$$x^6 = h_3 \,.\, x^3 + (qh_2 + rh_1 + s)x_2 + (rh_2 + sh_1)x + sh_2 \,.$$

Now assume

$$x^n = h_{n-3} \,.\, x^3 + (qh_{n-4} + rh_{n-5} + sh_{n-6}) \,.\, x^2$$
$$+ (rh_{n-4} + sh_{n-5})x + sh_{n-4} ;$$

operating on this equation in like manner we shall get, since by the lemma $ph_{n-3} + qh_{n-4} + rh_{n-5} + sh_{n-6} = h_{n-2}$,

$$x^{n+1} = h_{n-2}x^3 + (qh_{n-3} + rh_{n-4} + sh_{n-5})x^2$$
$$+ (rh_{n-3} + sh_{n-4})x + sh_{n-3} ,$$

which proves the preposition in a particular case.

The general case is established in a similar way,

$$x^m = p_1x^{m-1} + p_2x^{m-2} + p_3x^{m-3} + \ldots + p_m \,.$$

Multiplying both sides of this equation by x, writing for x^m its equivalent value, and arranging the terms, we shall get, since by the lemma $p_1h_1 + p_2 = h_2$,

$$x^{m+1} = h_2 \,.\, x^{m-1} + (p_2h_1 + p_3)x^{m-2} + (p_3h_1 + p_4)x^{m-3}$$
$$+ \ldots + (p_{m-1} \,.\, h_1 + p_m) \,.\, x + p_m \,.\, h_1 \,.$$

Applying the same process to this equation, it may be shown, since $p_1h_2 + p_2h_1 + p_3 = h_3$, that

$$x^{m+2} = h_3 \,.\, x^{m-1} + (p_2h_2 + p_3h_1 + p_4)x^{m-2} + (p_3h_2 + p_4h_1 + p_5)x^{m-3}$$
$$+ \ldots + (p_{m-1} \,.\, h_2 + p_m \,.\, h_1)x + p_m \,.\, h_2 \,.$$

Now assume

$$x^n = h_{n-m+1} \cdot x^{m-1}$$
$$+ (p_2 \cdot h_{n-m} + p_3 \cdot h_{n-m-1} + p_4 \cdot h_{n-m-2} + \ldots + p_m \cdot h_{n-2m+2}) \cdot x^{m-2}$$
$$+ (p_3 \cdot h_{n-m} + p_4 \cdot h_{n-m-1} + p_5 \cdot h_{n-m-2} + \ldots + p_m \cdot h_{n-2m+3}) \cdot x^{m-3}$$
$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$
$$+ (p_r \cdot h_{n-m} + p_{r+1} \cdot h_{n-m-1} + p_{r+2} \cdot h_{n-m-2} + \ldots + p_m \cdot h_{n-2m+r}) \cdot x^{m-r}$$
$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$
$$+ (p_{m-1} \cdot h_{n-m} + p_m \cdot h_{n-m-1}) \cdot x$$
$$+ p_m \cdot h_{n-m} ;$$

operating on this equation in like manner it may be finally shown, since by the lemma

$$p_1 \cdot h_{n-m+1} + p_2 \cdot h_{n-m} + p_3 \cdot h_{n-m-1} + \ldots + p_m \cdot h_{n-2m+2} = h_{n-m+2}$$

that

$$x^{n+1} = h_{n-m+2} \cdot x^{m-1}$$
$$+ (p_2 \cdot h_{n-m+1} + p_3 \cdot h_{n-m} + p_4 \cdot h_{n-m-1} + \ldots + p_m \cdot h_{n-2m+3}) \cdot x^{m-2}$$
$$+ (p_3 \cdot h_{n-m+1} + p_4 \cdot h_{n-m} + p_5 \cdot h_{n-m-1} + \ldots + p_m \cdot h_{n-2m+4}) \cdot x^{m-3}$$
$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$
$$+ (p_r \cdot h_{n-m+1} + p_{r+1} \cdot h_{n-m} + p_{r+2} \cdot h_{n-m-1} + \ldots + p_m \cdot h_{n-2m+r+1}) \cdot x^{m-r}$$
$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$
$$+ (p_{m-1} \cdot h_{n-m+1} + p_m \cdot h_{n-m}) \cdot x$$
$$+ p_m \cdot h_{n-m+1} \cdot$$

Thus the proposition is completely established.

3. The following extensions of the foregoing lemma, particularly in the case of a quadratic, may be worthy of notice.

If α, β be roots of $x^2 = px + q$, then

$$h_n = p \cdot h_{n-1} + qh_{n-2} \quad . \quad . \quad . \quad (1),$$

where h_n is the sum of the homogeneous products of α, β of n dimensions.

Repeating the principle contained in (1) we find

$$h_n = p^2 \cdot h_{n-2} + 2pq \cdot h_{n-3} + q^2 \cdot h_{n-4}$$
$$= (p+q) \cdot [h]_{n-4}^{n-2} \text{ symbolically} \quad . \quad . \quad (2).$$

Applying the same principle to (2), we shall also get

$$h_n = p^3 \,.\, h_{n-3} + 3p^2q \,.\, h_{n-4} + 3pq^2 \,.\, h_{n-5} + q^3 \,.\, h_{n-6}$$
$$= (p+q)^3 \,.\, [h]^{n-3}_{n-6} \,;$$

and in like manner

$$= (p+q)^4 \,.\, [h]^{n-4}_{n-8}$$
$$= \qquad .$$

while generally

$$h_n = p_r \,.\, h_{n-r} + rp^{r-1}q \,.\, h_{n-r-1} + \frac{r(r-1)}{1\,.\,2} \,.\, p^{r-2}q^2 \,.\, h_{n-r-2}$$
$$+ \ldots + q^r \,.\, h_{n-2r}$$
$$= (p+q)^r \,.\, [h]^{n-r}_{n-2r} \text{ symbolically} \quad . \quad . \quad . \quad (3).$$

Again, h_n may be expressed under another form—in terms of the coefficients of the equation (p and q) only. Here it will be necessary to distinguish the cases n even and odd.

We have

$$h_1 = p \,;\; h_2 = ph_1 + q = p^2 + q \,,$$
$$h_3 = ph_2 + qh_1 = p^3 + 2pq \,.$$

By repeated applications of formula (1) we may deduce

$$h_8 = p^8 + 7p^6q + 15p^4q^2 + 10p^2q^3 + q^4 \,,$$
$$h_9 = p^9 + 8p^7q + 21p^5q^2 + 20p^3q^3 + 5pq^4 \,,$$

. . . . .

and generally

$$h_{2n} = p^{2n} + (2n-1) \,.\, p^{2n-2} \,.\, q + \frac{(2n-2)(2n-3)}{1\,.\,2} \,.\, p^{2n-4} \,.\, q^2$$
$$+ \frac{(2n-3)(2n-4)(2n-5)}{1\,.\,2\,.\,3} \,.\, p^{2n-6} \,.\, q^3 + \ldots + \frac{(n+1)n}{1\,.\,2} \,.\, p^2q^{n-1}$$
$$+ q^n \,. \quad . \quad . \quad . \quad (4),$$

and

$$h_{2n+1} = p^{2n+1} + 2np^{2n-1}q + \frac{(2n-1)(2n-2)}{1\,.\,2} \,.\, p^{2n-3} \,.\, q^2$$
$$+ \frac{(2n-2)(2n-3)(2n-4)}{1\,.\,2\,.\,3} \,.\, p^{2n-5} \,.\, q^3 + \ldots + \frac{(n+2)(n+1)n}{1\,.\,2\,.\,3} \,.\, p^3q^{n-1}$$
$$+ (n+1)pq^n \quad . \quad . \quad (5),$$

each of which series consists of $n+1$ terms.

Conversely, the sums of the series (4) and (5) are known; for they are respectively h_{2n} and h_{2n+1}, that is

$$(\alpha^{2n+1} - \beta^{2n+1}) \div (\alpha - \beta)$$

and

$$(\alpha^{2n+2} - \beta^{2n+2}) \div (\alpha - \beta) .$$

4. To obtain results corresponding to (3) in the case of a cubic and of equations of a higher degree, we observe that in the case of a quadratic the number of terms in $(p+q)^r$ is the same as the number of different h's represented by $[h]_{n-2r}^{n-r}$.

Taking the equation

$$x^3 = px^2 + qx + r$$

we have

$$h_n = p \,.\, h_{n-1} + qh_{n-2} + r \,.\, h_{n-3} \quad . \quad . \qquad (6),$$

where h_n denotes the sum of the homogeneous products of roots of the cubic. By the repeated application of (6) we deduce

$$h_n = p^2 \,.\, h_{n-2} + 2pq \,.\, h_{n-3} + \ldots + r^2 \,.\, h_{n-6}$$
$$= (p+q+r)^2 \,.\, [h]_{n-6}^{n-2} \text{ symbolically,}$$

where we observe that h_{n-4} occurs twice.

Again, it will follow that

$$h_n = (p+q+r)^3 \,.\, [h]_{n-9}^{n-3},$$

the number of terms in $(p+q+r)^3$ being ten, while there are only seven different h's, h_{n-5}, h_{n-6}, h_{n-7} each occurring twice.

So it will follow that

$$h_n = (p+q+r)^4 \,.\, [h]_{n-12}^{n-4}$$
$$= (p+q+r)^5 \,.\, [h]_{n-15}^{n-5}$$
$$= \quad . \quad . \quad . \quad . \quad . \quad . \quad .$$

and generally

$$h_n = (p+q+r)^r \,.\, [h]_{n-3r}^{n-},$$

the number of different h's being $2r+1$, and so disposed that in the first pair each h occurs once, in the second pair each h occurs

twice, in the third three times, and so on up to the $\frac{r}{2}$th pair, while the middle h, *i.e.*, h_{n-2r}, occurs $\frac{r}{2}+1$ times. The same law holding when we reckon from the end, the total number of terms will be

$$4\left(1+2+3+\ldots+\frac{r}{2}\right)+\frac{r}{2}+1,$$

that is, $\frac{1}{2}(r+1)(r+2)$, which is the number of terms in $(p+q+r)^r$.

Again, if we consider the equation

$$x^4=px^3+qx^2+rx+s,$$

we have

$$h_n=p\,.\,h_{n-1}+q\,.\,h_{n-2}+r\,.\,h_{n-3}+s\,.\,h_{n-4},$$

from which it may be deduced in the same manner as before that

$$\begin{aligned}h_n&=p^2\,.\,h_{n-2}+2pq\,.\,h_{n-3}+\ldots+s^2\,.\,h_{n-8}\\&=(p+q+r+s)^2\,.\,[h]_{n\ \ 8}^{n-2}\text{ symbolically,}\end{aligned}$$

in which h_{n-4}, h_{n-5}, h_{n-} occur twice.

So it will follow that

$$\begin{aligned}h_n&=(p+q+r+s)^3\,.\,[h]_{n-12}^{n-3}\\&=(p+q+r+s)^4\,.\,[h]_{n\ \ 16}^{n\ \ 4}\\&=\ .\ \ .\ \ .\ \ .\ \ .\ \ .\ \ .\end{aligned}$$

and generally

$$h_n=(p+q+r+s)^r\,.\,[h]_{n-4r}^{n-r},$$

the number of different h's being $3r+1$, which are repeated by the same law in going from the beginning and the end, and such that the sum of the number of all their coefficients is equal to the sum of the series,

$$1+3+6+10+\ldots+\frac{1}{2}(r+1)(r+2)$$

that is

$$\frac{(r+1)(r+2)(r+3)}{1\,.\,2\,.\,3},$$

which is the number of terms in $(p+q+r+s)^r$.

Finally, in the case of the equation

$$x^m = p_1 x^{m-1} + p_2 \, . \, x^{m-2} + p_3 x^{m-3} + \ldots + p_m \, ,$$

since

$$h_n = p_1 \, . \, h_{n-1} + p_2 \, . \, h_{n-2} + p_3 \, . \, h_{n-3} + \ldots + p_m \, . \, h_{n-m} \, ,$$

it will follow in like manner that

$$\begin{aligned} h_n &= (p_1 + p_2 + p_3 + \ldots + p_m)^2 \, . \, [h]_{n-m.2}^{n-2} \\ &= (\quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad)^3 \, . \, [h]_{n-m.3}^{n-3} \\ &= (\quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad) \, . \, [h]_{n-m.4}^{n-4} \\ &= \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \end{aligned}$$

and generally

$$h_n = (p_1 + p_2 + p_3 + \ldots + p \;)^r \, . \, [h]_{n-mr}^{n-r} \, ,$$

the number of different h's being $(m-1)r+1$, which are repeated by the same law in going from the beginning and the end, and such that the sum of the number of all their coefficients is equal to the sum of the series,

$$1 + \frac{m-1}{1} + \frac{(m-1)m}{1\,.\,2} + \frac{(m-1)m(m+1)}{1\,.\,2\,.\,3} + \ldots$$
$$+ \frac{(r+1)\,(r+2)\,(r+3)\ldots(r+m-2)}{1\,.\,2\,.\,3 \ldots \;\; (m-2)} \, ,$$

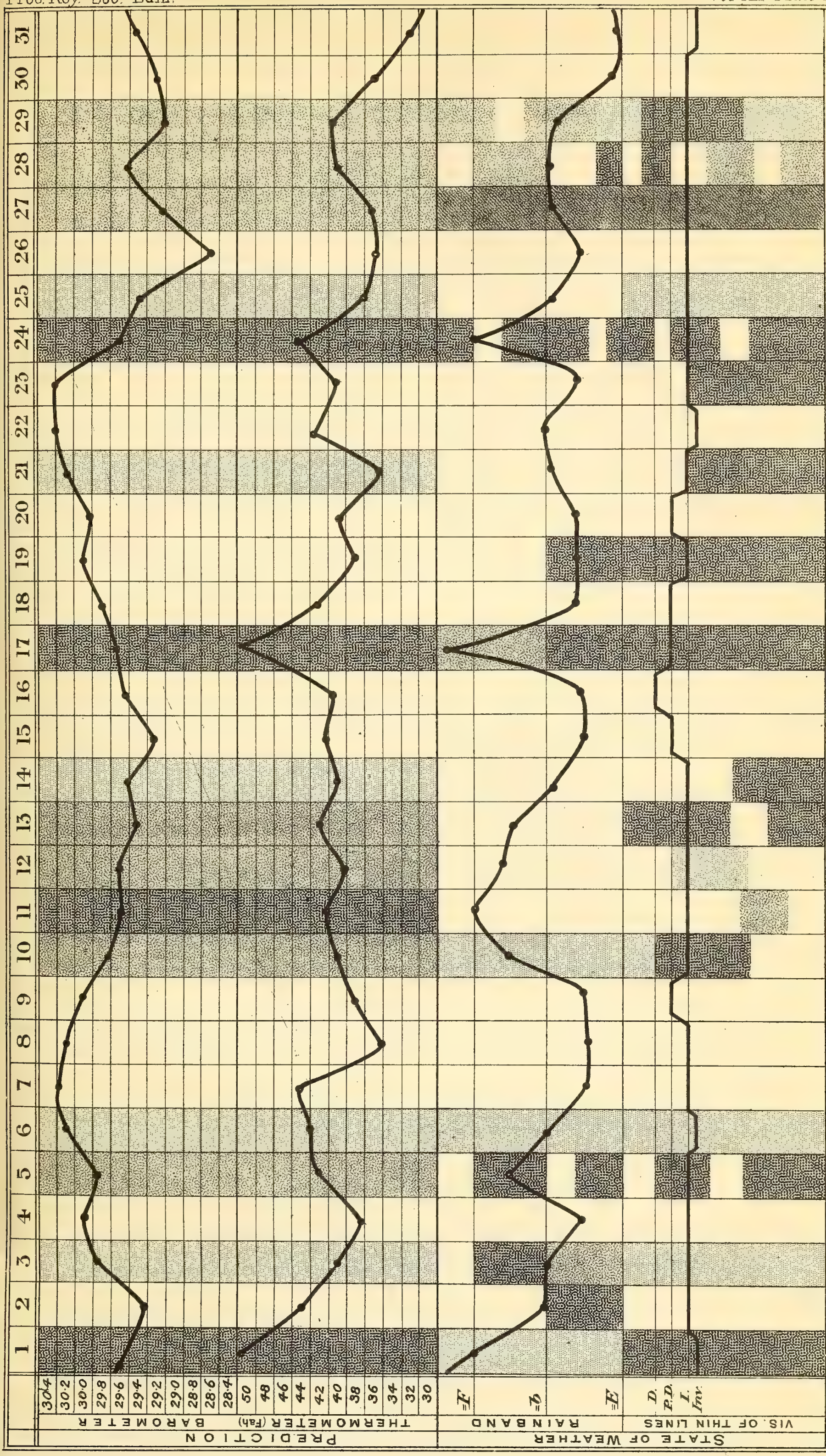
that is

$$\frac{(r+1)\,(r+2)\,(r+3)\ldots(r+m-1)}{1\,.\,2\,.\,3 \ldots \;\; (m-1)} \, ,$$

which is the number of terms in

$$(p_1 + p_2 + p_3 + \ldots + p_m)^r \, .$$

CHART FOR JANUARY 1883



Hugh Robert Mill, Delt.

J. Bartholomew, Edinr.

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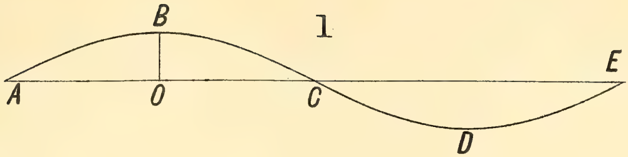

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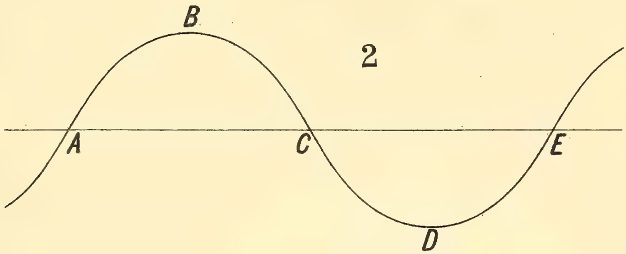

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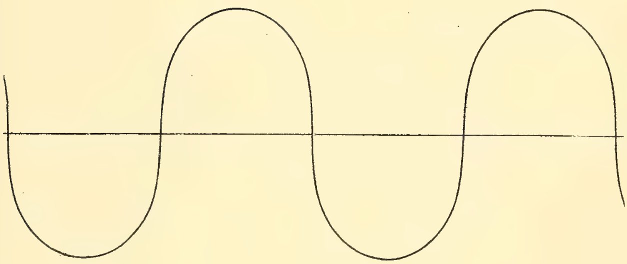

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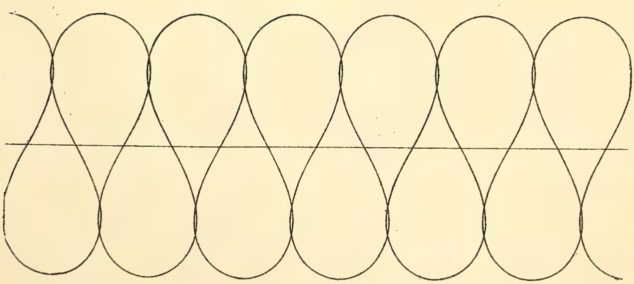

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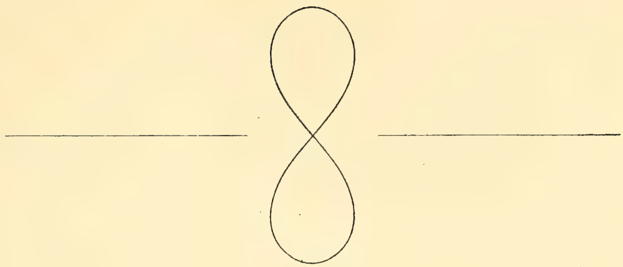

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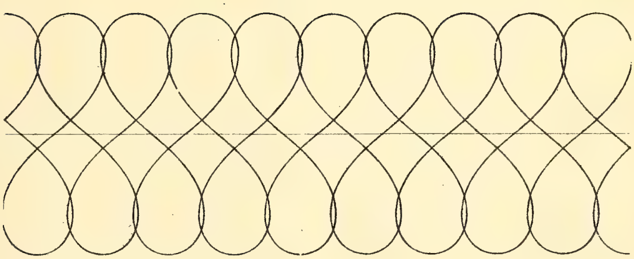

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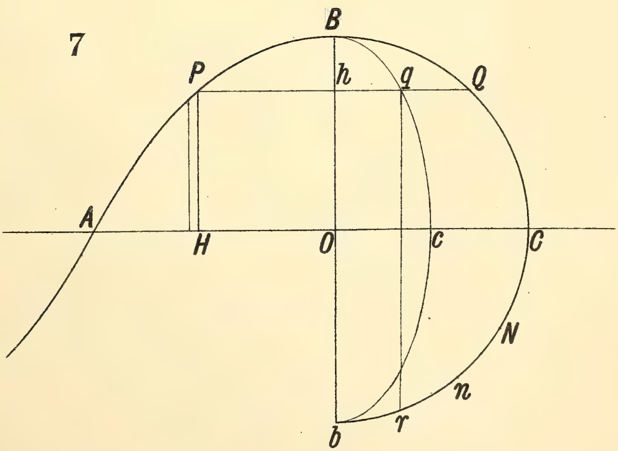

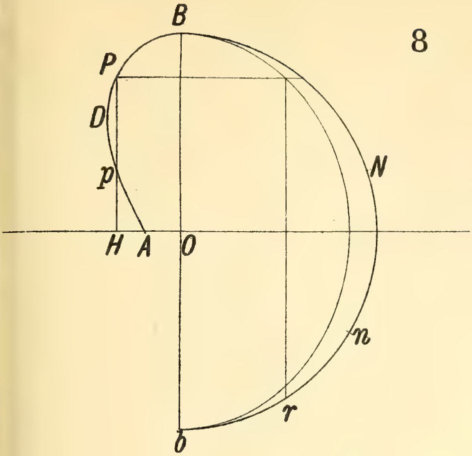
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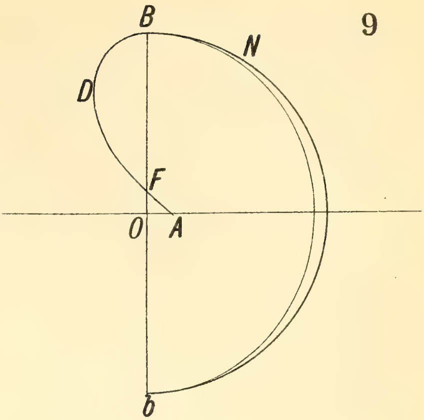
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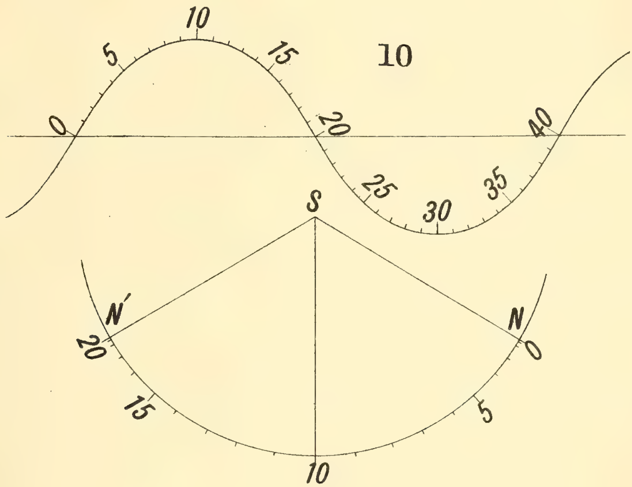
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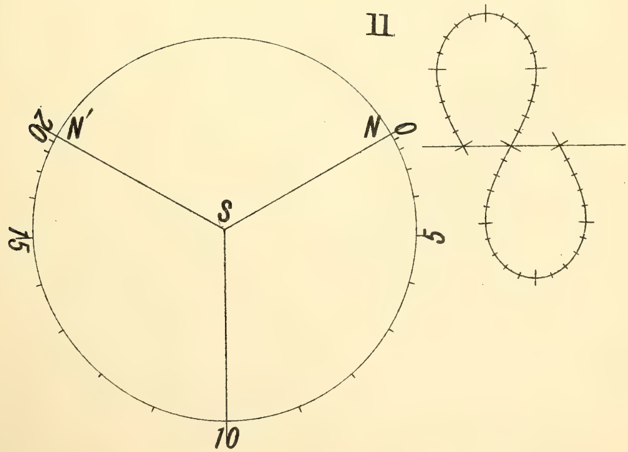
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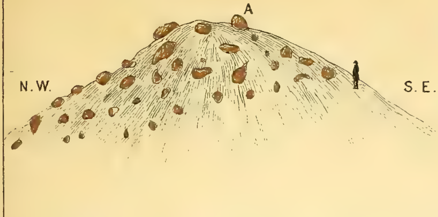
Diag. 1.

TOP OF HILL ON LOCH KILLESPORT COVERED WITH BOULDERS



Diag. 2.

INDIVIDUAL BOULDERS FROM HILL SHOWN IN FIG. I
LOCH KILLESPORT

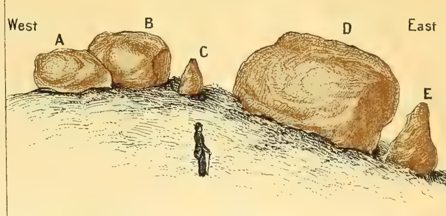
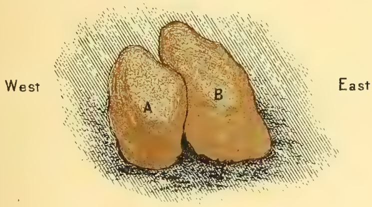


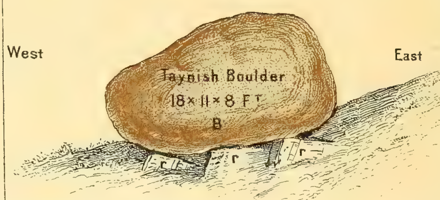
Fig. 3.

ONE BOULDER LEANING ON ANOTHER ON THE HILL IN FIG. I
LOCH KILLESPORT



Diag. 4.

LOCH KILLESPORT



Diag. 5.

TAYNISH LOCH KILLESPORT
SMOOTHED ROCK COVERED BY BOULDERS
ROCK FACE SLOPES DOWN WESTWARD

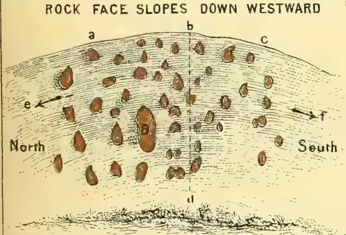
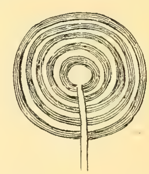


Fig. 7.

LOCH SWEYN
ROCK SURFACE SMOOTHED AND STRIATED,
WITH HOLES ON SURFACE
Length about 25 F^t Breadth 8 F^t

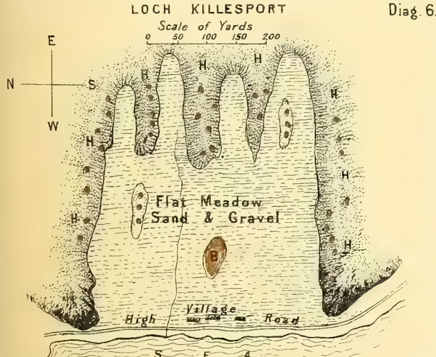
Fig. 9

SPECIMEN OF CUP MARKS
ON GLACIATED ROCKS
LOCH GILP HEAD 1 FT WIDE



Diag. 6.

LOCH KILLESPORT



Diag. 8.

LOCH SWEYN
BOULDERS ON HILL SIDE, HEAPED ON ONE ANOTHER

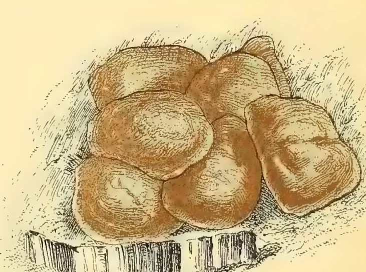
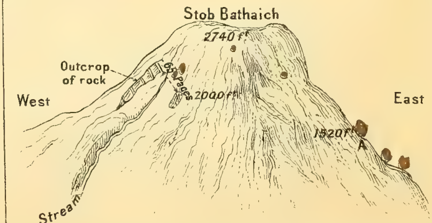


Fig. 10

BOULDERS, PERCHED ON RIDGE, & SUMMIT OF A HILL
BEIN-NAN-CLACH, GLEN DOCHART, PERTHSHIRE

Fig. 11

LOCH CLUNIE DISTRICT, INVERNESS-SHIRE



W & A. K. Johnston. Edinburgh.

PROCEEDINGS

OF THE

ROYAL SOCIETY OF EDINBURGH.

VOL. XII. 1883–84. No. 115.

GENERAL STATUTORY MEETING.

Monday, 26th November 1883.

THOMAS STEVENSON, Esq., Vice-President, in the Chair.

The following Council were elected :—

President.

THE RIGHT HON. LORD MONCREIFF.

Vice-Presidents.

Prof. H. C. FLEEMING JENKIN, F.R.S.
Rev. W. LINDSAY ALEXANDER, D.D.
THOMAS STEVENSON, M.Inst.C.E.
ROBERT GRAY, Esq.
A. FORBES IRVINE, Esq. of Drum.
EDWARD SANG, LL.D.

General Secretary—Professor TAIT.

Secretaries to Ordinary Meetings.

Professor TURNER, F.R.S.
Professor CRUM BROWN, F.R.S.

Treasurer.—ADAM GILLIES SMITH, Esq., C.A.

Curator of Library and Museum—ALEXANDER BUCHAN, Esq., M.A.

Councillors.

Rev. Professor DUNS.
Dr RAMSAY TRAQUAIR.
JOHN MURRAY, Esq.
WM. FERGUSON, Esq. of Kinmundy.
Professor COSSAR EWART.
Professor JAMES GEIKIE, F.R.S.
Rev. Dr W. ROBERTSON SMITH.
STAIR AGNEW, Esq., Registrar-Gen.
Prof. DOUGLAS MACLAGAN, M.D.
The Hon. Lord MACLAREN.
Rev. Professor FLINT, D.D.
Professor T. R. FRASER, M.D.

By a Resolution of the Society (19th January 1880) the following Hon. Vice-Presidents, having filled the office of President, are also Members of the Council :—

HIS GRACE THE DUKE OF ARGYLL, K.T., D.C.L.
SIR WILLIAM THOMSON, LL.D., D.C.L., F.R.S., Foreign Associate of Institute of France.

Monday, 3rd December 1883.

The Right Hon. LORD MONCREIFF, President, in the Chair.

The following Communications were read:—

1. An Essay upon the Limitations in Time of Conscious Sensations. By John B. Haycraft, M.B. Edin., F.R.S.E., &c.; Professor of Physiology in the Mason Science College, and Lecturer on Physiology at Queen's College, Birmingham.

I propose to describe in this essay some experiments which I have conducted upon the limits in time of separate tactile and thermal sensibilities. I shall endeavour to account for the variations seen in the limitations in conscious sensation of the different senses; and also to formulate a general proposition as to the effect on consciousness of stimuli increasing gradually in rapidity of application.

If the finger be touched with a pin, one is both conscious of the point in time at which the contact is made, and also when it is broken; this is likewise true of the other sensations. In the case of hearing, for example, a note struck upon the pianoforte is localised in time as of a certain duration. In moving an object through the field of vision, it is seen definitely to pass into, and also out of that field.

There is, however, a limit to this which can be determined, for if the image just alluded to be brought—by means of a revolving wheel—fifteen or twenty times a second in front of the same point of the visual field, it will now be seen as a stationary object, and the separate stimuli will produce a continuous sensation. In the case of hearing, Helmholtz has shown (*The Sensation of Tone as a Physiological Basis for the Theory of Music*, p. 262) that the limits in time are sharper and more exact. The ear can, according to this observer, distinguish 132 beats (produced by high notes) in a second; even this being probably not the extreme limit. It is also known that over 1400 impacts from a revolving toothed wheel must

affect the finger tip in a second, before the sensations are completely fused in consciousness; and before it becomes indistinguishable from a revolving smooth metal disc.

It is, then, to be noted that stimuli, separate in themselves, are, when sufficiently rapid, formulated in consciousness as continuous and uninterrupted; and that this fusion occurs sooner in the consciousness of some sensations than in others.

Some experiments which I have lately performed shed, I think, some light on these facts, and enable us to state them in greater amplitude; above all indicating *where* the fusion occurs. I may anticipate by stating that this is during the transformation of the stimuli into nerve energy.

My experiments have been chiefly concerned with the investigation of the results in consciousness of repeated stimulation of the nerves of tactile and thermal sensibilities, the apparatus being usually of the simplest possible kind.

The skin was stimulated interruptedly in many ways, either by tuning forks of various degrees of pitch, or by a revolving toothed wheel. The most satisfactory results, however, were obtained by a vibrating steel rod fixed in an iron vice. By altering its fixed point, and therefore the length of the vibrating portion, the period of its vibrations, and the impacts made upon the finger tip held near its free end, could be altered at will. Its exact pitch was easily obtained by attaching to it a light writing style which recorded its vibrations on a revolving smoked cylinder.

If the finger be pressed lightly upon a revolving toothed wheel, whose motion is made to increase slowly in rapidity, the following sensations may be noted. When no more than forty or fifty taps are made upon the finger in a second, there is produced a consciousness of distinct stimuli, separated one from another by periods of rest. Each stimulus produces a distinct sensation, limited in time from the one that follows. Stimulate more rapidly, and it becomes no longer possible to distinguish in consciousness one stimulus from another. They give rise, however, to a sensation which we term "roughness," which becomes less marked—less rough—as we increase the rapidity of the revolving wheel. If, at this point, the fingers be very gently pressed against the wheel, there is a sensation of tickling—such as that produced by drawing a feather over the

face. If, as a final step in the experiment, we cause the wheel to revolve very rapidly, the sensation becomes less rough, and, at last, when as many as 1400 impacts are made upon the finger tip, the sensation cannot be distinguished from that of a revolving toothless metal disc. There is, in fact, a sensation of "smoothness," which, but for the shearing produced upon the skin, could not be distinguished from the "touch" of a stationary smooth metal surface. We see then that three distinguishable conditions are produced by stimulating the skin more and more rapidly. At first, each stimulation is formulated separately in consciousness, then we have a sensation of roughness, and finally one of smoothness.

Before proceeding further it will be well to insist upon the fact, that when we consider the subject more generally, we can find analogous conditions in the other sensations. There is certainly in hearing and sight, for instance, a period of "roughness," which is irritating in its nature, and is a distinct sensation preceding the complete fusion of the stimuli in consciousness. Moreover, the nature of its cause is known only by experience gained from other sensations; it not being evident in the consciousness of the special sensations above mentioned.

The tick of a watch is not irritating—on the contrary, it may produce hypnotism. An alarum with more rapidly repeated sounds has a well known effect, upon which it will be needless to insist. My colleague, Professor Poynting, suggests that the very low notes of a large organ are, in like manner, irritating from their rapid intermittence. In the numbers quoted from Helmholtz, probably the "beats" are no longer separately heard, but produce the harsh dissonance which characterises them; a much lower number would indicate the number of stimuli which can be heard separately. This number I am unable to state, as a double syren is not in my possession.

Few things are more annoying than the flickering of a gas jet, or the slow vibration of a body which gives a blurred unsteady image. The tickling of a vibrating tuning fork held to the lips, or still more the tickling that results from stimulating in rapid succession adjacent points of the skin, is calculated in extreme cases to give excruciating agony.

A few minutes' consideration will also show that this condition of

"roughness" is *not* a sensation of intermittent stimulation. That this is its cause is but a matter of experience aided by the use of the other senses. A child blowing the sharp edge of a piece of tissue paper stretched between its lips, remarks that "it tickles," but is quite unaware of the cause of the sensation. Again, on touching the rapidly revolving wheel, it is conscious only of a continuous sensation; but turn it more slowly, and it feels each separate tap.

We have then in tactile sensibility a condition analogous to the cause of dissonance in music, and to the annoying flickering of recurrent visual stimuli. Moreover, we can recognise degrees or qualities of this "roughness," a most important factor in adding to our knowledge of the external universe. On drawing a file, or the edge of a fine saw across the finger, the sensation is quite different from that produced by the back of a knife. Moreover, within limits, we can distinguish a coarse from a fine file. The sensation in each case is different, and experience especially gained by the use of the eye, tells us of the nature of the substance which has produced the feeling.

It is a well known fact that all parts of the skin are not equally sensitive. The skin of the finger-tips and the front of the hand can be stimulated by the impact of a lighter body than will affect the skin of the back of the hand. Again, the skin of the front of the arm is more sensitive than that of the dorsal surface, and still more so than the skin covering the back of the shoulders. Together with this difference in actual sensitiveness, the brain is unable to localise impacts which affect the less sensitive parts, so exactly as those which affect the more sensitive. As a result of this, two impacts made on points of the skin near enough may be fused into one in consciousness. If the points of a pair of compasses less than one millimetre apart touch the finger-tip they may be distinguished as two, the localisation of each point in consciousness being very exact. Over the back, however, the points must be removed for more than an inch before they can be distinguished. This difference, not to be discussed here, is probably due to the anatomical distribution of the peripheral nerves.

It becomes an interesting question whether the limits in time of conscious tactile sensations vary in like manner over different surfaces of the body.

As a result of my experiments I am led to believe that, whereas the limitations in space are widely different, this does not hold with the limitations in time.

If a rod vibrating about forty times in a second be held to the finger tips or lips, sensations of distinct impacts may be felt. Allow the rod to vibrate upon a surface less sensitive, and with much wider limitations in space, say the skin over the sternum, and the impacts are still felt as such. I should mention that, inasmuch as the skin is less sensitive, the amplitude of the vibrations, and therefore the force of the impacts, should be increased.

So far we have considered the limitation in time of tactile sensibility; but there remains another very important fnnction of the skin, which we have to discuss. I refer to thermal sensibility.

On touching a good conductor, such as an iron ball, any difference of temperature will not at once be noted, the cold will not be felt instantly. On withdrawing the ball, the sensation of cold remains for a short time. The limits in time are very wide, for the application of the cold body on several successive occasions—even with intervals of a second—producing, of course, successive sensations of impact, gives rise to a continuous and uniform sensation of cold. If the good conductor be applied every second to the skin of the back or arm, distinct sensations of cold will be produced each time. This is not due to these parts being covered and sensitive to cold, for the same obtains with the thin skin between the fingers, and the back of the hand, although in a less degree. The difference must alone be due to the variations in thickness of the epidermis—a bad conductor—which separates the body touched from the nerve end-organs in the lower layers of the skin.

In studying these phenomena, I have used a very simple piece of apparatus. A long and slowly vibrating rod is fixed in an iron vice, and to its free end a small glass bottle is attached. This is fitted with a cork, through which passes an iron rod about half an inch wide. The bottle is filled with a mixture of ice and salt, which cools the rod in its whole length. The portion outside the bottle is caused to impinge upon the finger-tip periodically.

In order that the action of external stimuli may affect our consciousness, a certain period of time is necessary. This period varies with many factors which we propose to discuss. A correct estima-

tion of the value of these factors is all the more necessary, as they are hopelessly confounded in most works on mental science.

We have, first, the irritation of the peripheral sensitive nerve; secondly, the transmission of some change thus produced in the nerve; and thirdly, that effect produced upon centrally placed nerve-cells associated with the production of feeling, and a consciousness of that feeling. The time elapsing between the impact of a body on the hand and the consciousness of that impact is much less than between the application of a drop of sugar solution to the tongue and the resulting sensation of sweetness. This period is different in the case of each sensation. On what does this depend? I shall endeavour to show that the dependence is not mainly on differences of time taken by the impression to pass along different nerves, nor need we look to differences affecting central cells; but we have, in the nature of the stimulus applied and in that of the stimulated end-organ, a cause which will account for everything.

Herbert Spencer, in his *Principles of Psychology* (vol. i. p. 169, third edition), would actually distinguish between peripherally initiated feelings caused by internal disturbances—some of which, he says, are extremely indefinite, and few or none definite in a high degree—and feelings caused by external disturbances which are mostly related quite closely, alike by coexistence and sequence, among the highest of them the mutual limitations in time and space or both being extremely sharp. He illustrates this by the fact that our states of consciousness in connection with vision and hearing are more sharply limited in time and space than those in connection with smell and taste, and, still more, hunger.

Now, discarding the fact that when considered developmentally the retina at any rate is far more *internal* than the mouth and nose, the former being really a portion of the brain, the latter puckerings-in of the surface, I would suggest, that the all-important factor producing this difference, is not the brain, or the produced feelings, as Herbert Spencer seems to me to indicate, but the nature of the peripheral end-organ stimulated. If the point of a pin impinges upon the finger tip, the epithelium is depressed, and at the same time the nerves of tactile sensibility are stimulated; and on withdrawing the pin, they are at that moment unstimulated, and in a condition of rest. Also in the ear, the sound vibrations

travelling rapidly into the internal ear cause the structures there (the basilar membrane and rods of Corti) to vibrate, and—as we are aware from our knowledge of the action of one vibrating body upon another—they do this very rapidly.

Far otherwise with the senses of smell and taste. When odorous particles pass into the olfactory or upper part of the nasal cavity—in which the nerves of smell are placed—it is by diffusion from the lower or respiratory part of the nose. If the breath be held, and a piece of incense paper be burnt in front of the face, some time may elapse before the scent is perceived, because the odorous particles have in fact to diffuse into a closed sac. If, on the other hand, the experimenter "sniffs" the air, the stimulus will be more rapidly perceived, because the odorous particles are carried rapidly through the lower chamber of the nose, inducing out-currents from the upper chamber, which consequently becomes immediately filled by odorous particles. In like manner, the closed sac has to get rid of odorous particles from within it by this same slow process of diffusion, before the odour ceases to be felt. From the nature of the stimulation and position of the end-organ, the limitations in time of the sensations are not well marked.

In the case of the sense of taste, the same holds true. Substances held in solution are alone tasted; the tongue is covered with a layer of mucin derived from mucous and salivary glands, and the nerves are not superficial but embedded in the epithelial covering. It will be easily understood, that in this case also, the accession of a sensation must, from the nature of the stimulus, and the position of the end-organ, be gradual in its production and slow in passing off, and therefore not strictly limited in time. The watery solution has to mix in the first place with the mucin covering the tongue before it can reach the end-organs situated in the epithelium.

In the case of hunger again, the limitations in time are due entirely to a condition of things other than mental. The fulness of the alimentary canal is associated with a feeling of comfort, and when no food is present therewith a feeling of hunger; and as there is every conceivable transition between a condition of full stomach and an empty one, so the passage of the one sensation into the other must pass through innumerable transition states.

If it be needed, another example may be mentioned in the case

of the cold body applied to the horny tip of the finger, and to the thin skin covering the sides. The nerve-endings are stimulated by the addition or withdrawal of heat from the nerves of the skin. This is gradual, and does not correspond to the application of the cold body to the surface because of the horny epithelial covering. Where this covering is thin, the limitation in time of the sensation is more definite than where it is thick; and could we apply the cold body directly to the nerve end-organ, the limits would then be very sharply defined. Cover the hand with a glove, and the limits would be very ill-defined indeed.

Sufficient evidence has, I think, been adduced to show, that where the limits of a sensation are not well defined in time, we may conclude that this is not due to anything in the nature of the sensorium, but depends upon the way the external energy is changed into nerve energy in the terminal end-organ.

Let me define a sensation as the result of a transformation of the energy travelling along a nerve of sensation from without, into the energy manifested by the nerve cell to which it passes. We have, I insist, no reason to doubt that if that nerve energy travelled twenty times a second along a nerve of smell, of taste, hearing, or of sight, we should be conscious of twenty separate sensations in each case.

That such a transmission is impossible in every case we know, but it is due to the fact that in these cases the nerve cannot be stimulated from without so frequently.

In the case of the ear, the limits in time of high notes are sharper than those of the low notes, and probably this is due to a better damping apparatus in the ear. Could we increase the perfection of this damping, the limits of the consciousness in hearing would probably be sharpened almost indefinitely, for we must remember that the cause of the different sensations of sound is a difference of pitch, or periods of stimulation recurrent in time to which the sensorium is extremely sensitive.

If this be true, the period of time taken by a stimulus to produce a sensation depending upon the time taken by its energy to be transformed into nerve energy in the peripheral end-organ, will be some indication of the manner of this transformation. For instance, there is a very marked interval between the moment at which the

rays of light strike the retina, and the production of the sensation; and further, the sensation remains for some time after withdrawal of the stimulus. It is unlikely, therefore, that the energy of light is directly transformed into nerve energy.

In shortly summing up the chief points alluded to in this paper, it may be stated—

(1) That stimuli applied to sensitive peripheral end-organs with increasing frequency, produce at first consciousness of the separate stimuli; then, their individual characters are lost, and a disagreeable sensation—"roughness" in the case of tactile feeling—is produced; and lastly, we feel a sensation indistinguishable from a constantly applied stimulus.

(2) For the development of nerve energy from external stimuli in a sensory nerve a latent period is necessary, and it elapses between the application of the stimulus and the resultant effect on the nerve. On withdrawing the stimulus, the nerve is still in a condition of activity, and remains so for a certain period (after-period). When this nervous energy is transformed into nerve-cell energy in the sensory centres, there is probably neither a well-marked latent nor an after-period.

(3) When, as in the sense of touch, the consciousness of the stimulus corresponds more exactly in time with the application of the stimulus than in the sense of sight, we are to look not to any differences in the limitation of consciousness itself, but to the time elapsing in each case before the nerve is excited by the stimulus and the length of the corresponding after-period.

2. The Old English Mile. By Wm. Flinders Petrie. Communicated by Professor Robertson Smith.

The length of the old English mile has been hitherto so uncertain, that any fresh light upon it is well worthy of study; and an important source of information—the map in the Bodleian Library—has not yet been brought to bear upon the question. The present inquiry was suggested by the sight of this map, which seems to add so much to our knowledge that a review of the whole subject has become desirable. It is proposed, therefore, in this paper to bring together all the data worth consideration, beginning with the most

recent; and by deducing what the mean conclusion is from each source, to be thus able to compare together the various results, and so arrive at some definite statements within known limits of uncertainty.

The only discussion of the subject that has yet been made is that by Professor de Morgan* in the article "Mile," in the *Penny Cyclopœdia;* in other encyclopædias no notice is taken of the history of the English mile, and D'Anville makes only a rough deduction as to the old mile being longer than the statute mile; he uses but few data, complicates these with unproved theories, and is somewhat vague in his statements.†

It will be necessary first to briefly mention some of the conclusions in De Morgan's most valuable article in order to point out their bearing on the inquiry. In beginning the article he seems strongly inclined to disbelieve in the existence of any old mile longer than the statute mile, mainly relying on the fact of Bernard (1688) and Greaves (1647) not describing any longer mile. He says, "on the authority of the silence of Bernard and Greaves above referred to, we must remain of a contrary opinion (*i.e.*, to D'Anville), and must suppose that the computed miles preserved by Ogilby (1675) had been intended to represent the number of statute miles, but erroneously given. What then may these computed miles mean which had served the common purpose in the estimation of distances? The word computed never meant reputed, but was always applied to a result of reckoning of some kind or other." Now it so happens that, in the *Traveller's Guide* (1699)‡ (a typographical edition of Ogilby's Atlas), these miles are variously described as "computed," "vulgar computation," and "reputed;" so that the objection raised by De Morgan to their being those in common repute and use is not borne out by the name employed. He notices Ogilby's guess that the computed distances read a less number by omitting the lengths of the towns; and, rejecting that idea as an insufficient explanation (as it certainly is), he concludes

* *Notes and Queries*, i. xii. 195.

† As when he describes 15·2 miles as being "quelque chose de plus que 14," in *Mésures Itineraires*, chap. x.

‡ De Morgan does not seem to have seen this book at all, as he refers to *The Complete Tradesman*, by N. H. (1684), as giving the lists of computed and measured miles, which this edition of Ogilby gives far more completely.

that the "computed" distances were derived from the straight-line measurements of statute miles from a map, thus omitting the length of windings of the roads. But this explanation also is quite insufficient, as, in the first place, the windings will not account for even as much as half of the difference of numbers of computed or reputed and statute miles; secondly, the difference between computed and statute miles exists just as plainly on the straight Roman roads, where no windings exist, as on the winding roads; and finally, as we shall see, these computed miles are the same as those in use in the thirteenth century, when maps were very scarce, and it is quite unlikely that the populace should have adopted their current reckoning of every-day journeys from the measurements of a few distorted monastic manuscripts. Hence, De Morgan's explanation is certainly insufficient; and in the latter part of his article he argues for an old mile equal to $1\frac{1}{2}$ statute miles, concluding thus: "We think it by no means improbable that 100 ancient miles are as much as 150 statute miles, and tolerably certain that they exceeded 145 such miles." Thus he agrees with Sir Henry Ellis, who writes, "the ordinary mile of England . . . . . was nearly a mile and a half of the present standard."*

A point on which De Morgan lays much stress is the shortening of the roads in modern times, and the much greater length he supposes them to have formerly been. The only evidence adduced is a comparison of four of the distances by Ogilby (1675) in statute miles with modern statements of the same, which may not have followed exactly the same route. But on measuring the modern distances† of about ninety of Ogilby's statements, there does not appear to be any constant difference between his reckoning and the present roads; and in single lengths Ogilby was certainly in error occasionally, since he sometimes gives a *less* distance than the shortest practicable line.‡ From a general consideration of the history of roads, and the

* *Introduction to Domesday Book* (1833), i. 145 *et seq.*

† The actual distances in statute miles are here ascertained from the county maps of *The National Gazeteer* (1865 ?); these are very clear, and appear to be accurate on comparison with the Ordnance Survey. The windings of the roads are in all cases carefully attended to in the measurement.

‡ *E.g.*, High Wycombe to Tetsworth, 12·0 Ogilby, =13·6 miles really; Prestein to Rhyadergowy, 12·7 Ogilby, =14·4, or more, really; Royston to Huntingdon, 19·2 Ogilby, =21·4, or more, really.

manifestly ancient course of most of them, it seems very unlikely that any notable alteration has taken place in their length since they were the first tracks through waste lands.

After what has been remarked above, there does not seem any reason for not taking the statements of distances in various books and maps to be what they profess to be, that is, the "reputed" or "vulgar" long miles between the places in question, reckoned exactly like the statements of the same distances in statute miles.

It may seem rather astonishing to see in all maps, until within recent years, such a careful definition of miles as "statute miles, $69\frac{1}{2}$ to $1°$"; but the need for this explicitness arose from the great confusion which existed between different miles. In Gibson's edition of *Camden* (1695) there are no less than three mile scales on nearly all the maps; these scales vary a good deal, but by measuring each of them, and a distance between two places on each map to give the true scale, the values of the three miles, "great," "middle," and "small," may be deduced.* On thus obtaining a value from each of the forty or more maps, and taking the mean result for each sort of mile, we find the miles to be respectively 1290 ± 16, 1167 ± 14, and 1037 ± 11 thousandths of the statute mile.† Now these values are very exactly in the proportion of 10, 9, and 8;‡ and since we cannot doubt but that 1037 was intended for the statute mile of 8 furlongs, it seems that these three miles were of 10, 9, and 8 furlongs respectively.

Next before this there is the great authority of Ogilby, the surveyor of England, to whom the first accurate road maps and measurements are due. He published his atlas, *Itinerarium Angliæ*, in 1675, stating the miles of "horizontal distance" (*i.e.*, as the crow flies), of "vulgar computation" (*i.e.*, the old long miles), and of "dimensuration" (*i.e.*, the statute miles measured by his perambula-

* The degrees on the borders of the maps cannot be trusted, as they bear no fixed relation to the miles, and the longitudes of the western counties are very erroneous.

† Throughout this paper all miles will be thus stated in thousandths of the statute mile.

‡ Thus, $1290 \div 10 = 129{\cdot}0 \pm 1{\cdot}6$.
$1167 \div 9 = 129{\cdot}7 \pm 1{\cdot}5$
$1037 \div 8 = 129{\cdot}6 \pm 1{\cdot}4$.

tor); but as he only gives the totals in this way, the details must be sought in the typographical edition of his work called *The Traveller's Guide* (1699).* For comparing the "computation," "vulgar computation," or "reputed" miles, with the real distances, Ogilby's statute miles have been here adopted, as he has no constant error in one direction, and his fluctuating errors are much less than those of the reputed miles, so that no further inaccuracy will be caused by taking his statement. In this investigation the roads were broken up into lengths of about forty miles each for purposes of comparison of the mile lengths; and besides this, there are shorter lengths of cross roads. The lengths compared together are in all 154 in number, of which 134 belong to the old mile, eight to the N.W. mile, and twelve to the Welsh mile. From the mean of these 134 lengths, the old mile appears as 1307 ± 5. The local miles we pass over for the present; but the posting miles which are given, though agreeing in general with the old miles, yet in nine cases are shorter, and in two cases a little longer; the shortest form is equal to the statute mile.

From Ogilby's work lists of miles were reprinted more or less abbreviated, as in the *The Complete Tradesman*, by N. H. (1684), which gives both "computed" and "measured" miles. In *The Exact Dealer*, by J. H. [John Hill] (1688), the miles are generally the reputed or long miles of Ogilby, but sometimes the post miles, or others. In *The Description and Use of two Arithmetick Instruments*, by Sir Samuel Morland (1673), just before Ogilby's publication, the miles are the same as the post miles in Ogilby, where they differ occasionally from Ogilby's reputed miles.

The next earlier information is in the maps of England commonly known as "The Quartermaster's Map" (1644). This gives a scale on each of the six sheets; and on measuring two distances on each sheet to obtain the absolute value, it appears that these maps are far more accurate than any others of that period, the average error being but a third of that of Saxton, Speed, or Gibson. The mile value from this source averages 1255 ± 10.

In the year before this *A Direction for the English Traveller*

* This is catalogued under Ogilby in Brit. Mus.; but he died in 1676. There is no editor's name to it.

(1643)* first appeared; this consists of a series of small copper-plate maps of each county with a cross-line table of the distances between places in the county, besides a similar plate of all England. The same plates were printed from again by the same publisher in *A Book of the Names of all Parishes*, &c. (1662 and 1668). Taking from each plate two of the distances stated between places in miles, and comparing the 73 distances thus extracted with the true road distances, the mean mile is 1375 ± 12. But this is so decidedly longer than the mean mile of any other authority, that it seems as if these distances had been compiled and tabulated by measurement from the plates, or from some older maps, in straight lines. If this were the case we should subtract about 7 per cent.,† and the true mile will then be 1280 ± 20, and thus in accordance with other authorities.

Speed's maps of counties preceded this by some time (1610); and on measuring the mile scale, and a distance between towns, on each plate, and then taking the mean of the 43 results, the mile comes out 1300 ± 12, omitting the Welsh counties.

Saxton's county maps (1575) also have scales, and were examined like Speed's for extracting the mile. From thirty plates the mean result is 1310 ± 16, omitting the Welsh as before.

William of Worcester (1473) gives measurements and distances continually, throughout his rambling note-book; and by extracting all the distances, his mean mile may be obtained. But it is not desirable to include any of less than 5 miles, as such are necessarily much less accurate, being only stated to single miles; and all sea distances, and rough statements of the dimensions of districts or countries, should be omitted. There then remain 92 distances, and on measuring all these on modern maps, it appears that his mile was 1310 ± 20.

Sir Gilbert de Lannoy's distances in Palestine (1422), quoted by De Morgan (article "Mile"), give by five examples a mean mile of 1180 ± 20, *plus* about 8 per cent. for winding of roads, and therefore probably about 1280 ± 20.

* Published by Thos. Jenner, under whose name it is catalogued in the Brit. Mus.

† By careful map-measurement of six long distances in England of 50 to 200 miles each, the excess due to windings is 127 on the 1000; and on short distances, of 12 to 25 miles, the windings make an increase of 66 on the 1000, beyond the direct distances in straight lines.

Roger Bacon's distances in Palestine (1253), also quoted by De Morgan, give by fifteen examples, a *leuca* equal to 2 miles of 1230 ± 60,* *plus* about 7 per cent. for windings, = 1320 ± 60. Neither this nor the previous statement are worth much, as they depend on the estimates of a few foreigners in a strange country, and not on the well-known reckoning of places where the writers and all their acquaintance had always lived, as in England.

We now come to what is the oldest authority, and also one of the most complete. This is the vellum map of England, Wales, and Scotland, in the Bodleian Library, which has the roads and distances marked on it throughout England and Wales. This map is attributed to the thirteenth century, and is by far the finest map known for such an early period. It is written in red with brown lines, and with the sea coloured green; and it is in very fair condition. It was published in copper-plate facsimile by Basine, with a partial description by Gough (to whom it belonged) in *British Topography*, i. 76 † (1780). It has also been published in coloured facsimile, with a key-plate of the names printed, in *National Monuments of Scotland*, part iii., edited by C. Innes. Basine omitted things altogether when he could not easily read them, and his renderings often differ from Gough's account. Generally his map has a better reading than Gough's text; but they both have many errors.‡ Gough continually omitted the numerals, even when Basine read them rightly; and he made curious mistakes in the places.§ Of course, no attempt was made to utilise the distance in such a manner of treatment. The facsimile by C. Innes is a fine piece of work, and apparently very correct; but the names are often omitted from the key-plate if hard to read; no attempt is made to supply lost names, by considering the positions of places; and the words have been merely read, as well as might be, without a reference to a modern map to check the reading.|| The main

* There is a manifest mistake in the place names; they should read Joppa to Cæsarea, Cæsarea to Aco, &c.

† The map in the Brit. Mus. copy is wrongly bound in at vol. ii. p. 76.

‡ For errors in common, see Colebrook to Maidenhead, x. in Gough and Basine, but vii. in Innes, which is the true reading by the distance; Whitby to Guisborough, xii. Basine, xiii. Gough, but xvii. Innes, the true reading.

§ *E.g.*, applying "Burgh" to Carlisle, while it belongs to a separate town on the map.

|| Thus there is the curious transcription of Coxton for Tuxford, of Lenning

attention of the editor was given (very properly in such a work) to the Scotch topography, and the far more valuable part of the map —as a map—was treated as an annex of little importance to the subject in hand. No attempt to transcribe or examine the mile distances was made either by Innes or by Gough.

When I saw this map at Oxford, and transcribed as well as I could * in an hour or two the lists of distances, it seemed very evident that all the distances in the south and east of England had been rewritten by some hand well accustomed to mediæval script; and this accounts for the ends of many words going off into a mere series of strokes, since the rewriter was not certain of part of the name, and just inked over what he could see. This rewriting deserves careful study in considering the map; and as it was apparently done before the sixteenth century, and the old writing must have been fading then, and yet is not illegible in parts even now, it is some evidence as to the great age of the map. What is now much needed is a critical examination of this map, identifying all the places by comparison with modern maps, and recovering any traces of the first writing of names and distances where it has become all but illegible. This work needs a good palæographer; but for the question of the miles, which is what we have at present to consider, such care is not required; for, if a few doubtful distances are omitted, it will not perceptibly affect our results. From a comparison of the readings of Basine, Gough, Innes, and my own notes, the distances may be pretty safely settled in all legible cases; and after omitting those in Wales and Cheshire, which show a different mile, there are 130 distances available for examination. The mean value of the old mile from these is 1265 ± 9.

Having now described the various data available for fixing the old mile, we will place the results all together and compare them, in terms of thousandths of the statute mile; stating the mean result from each source, the probable error (± , *i.e.*, what amount of variation the truth is as likely to exceed as to lie within), and the average error of a single length, which shows the relative accuracy of the different sources.

for Leeming, and the placing of Abergavenny on the west coast of Wales for a town which must be Aberdovy.

* The map is framed and glazed, and screwed high up against a pillar in a poor light; hence it is not easy to study.

A.D.			Mean mile.	Mean error.
1695	Gibson's maps,. . .	40 maps,	1290 ± 16	110
1675	Ogilby's numbers,.	134 distances,	1307 ± 5	65
1644	Quartermaster's map,	11 distances,	1255 ± 10	35
1643	Jenner's numbers, .	73 distances,	(1375 ± 12)	110
	or allowing for windings, probably		1280 ± 20	
1610	Speed's maps, . . .	43 maps,	1300 ± 12	90
1575	Saxton's maps, . .	30 maps,	1310 ± 16	100
1473	Wm. Worcester's notes,	92 distances,	1310 ± 20	200
1422	Lannoy's account, .	5 distances,	1280 ± 20	60
1253	Roger Bacon's account,	15 distances,	1320 ± 60	480
1250?	Bodleian map, .	130 distances,	1265 ± 9	120

The question now before us is, what probability is there of any change in the popular mile during the four centuries in which we have traced it? The possibility of change certainly lies within narrow limits, since (looking to the accurate authorities) the later examples cannot be taken to exceed 1307, nor the earlier to fall short of 1265.* Now, it is very unlikely that the Bodleian mile was as long as 1300, in fact it is more than 100 to 1 against its being so; therefore, the oldest form cannot be taken as a mere careless variant of Ogilby's value of 1307. Bacon, Lannoy, and William of Worcester are all too uncertain to decide on the difference in question. Coming down to the seventeenth century, the Quartermaster's maps, which agree very well among themselves, corroborate the earlier value, but we can hardly set them up against the large mass of information in Ogilby's tables.

On the whole, I should incline to fix the value of the old English mile at 1300 ± 10 during the end of the fifteenth and on to the seventeenth centuries, and to suppose that during the fourteenth century and the beginning of the fifteenth, it was lengthening from a value of 1265 ± 10, which it had in the thirteenth century. As it had lengthened thus, it is not improbable that the original value of it was still shorter, perhaps not exceeding 1250, or $1\frac{1}{4}$ statute miles. In any case the range of uncertainty is now reduced to very narrow limits,

* The mile in Italy having lengthened 1 per cent., though many of the old Roman milestones remained standing in the country, shows in which direction itinerary measures are likely to change.

compared with the vague conclusions that have been hitherto adopted.

We will now briefly notice the miles of the N.W. counties and of Wales. That a longer mile was in use in Lancashire, Cheshire, and Shropshire is certain both from the various authorities that we have just discussed agreeing in it, and also from the fact of a longer perch surviving in those parts.* On taking out the distances in Cheshire and Shropshire, they yield the following mile :—

Bodleian.	Wm. Worcester.	Saxton.
1540 ± 100	1570 ± 70	1420 ± 10
Speed.	Ogilby.	Gibson.
1340 ± 50	1400 ± 15	1385 ± 60

Lancashire is 1400 in Saxton, but comes down to the usual old mile in Speed and Ogilby. Thus it seems that the old N.W. mile was about 1560 ± 80, and was somewhat assimilated, as time went on, to the usual old mile of England, 1300 ± 10. There are not sufficient accurate data to allow of a complete disentanglement of local miles; but the Bodleian map distances in the eastern counties are not over the average, while later on they are higher. The southern and S.W. counties generally have a lower mile than the northern. But there is nothing necessarily to show more than accidental variation in the unit, except in the N.W. counties, considered above, and in Wales, which we will now notice. The Welsh distances give mile values of—

Bodleian.	Saxton.	Speed.	Ogilby.	Gibson.
1465 ± 45	1410 ± 20	1360 ± 20	1383 ± 20	No great mile.

Here there appears to have been an old mile of about 1460 ± 50, probably identical with the Cheshire mile; and, like that, gradually approximating to the usual old English standard.

The origin of the old English mile, which we have seen to be 1·265 statute miles, now remains to be considered.

* Lancashire perch $7\frac{1}{2}$ yards, therefore mile = 1·360 statute miles.
Cheshire ,, 8 ,, ,, = 1·460 ,,
—*Notes and Queries*, vi. i. 264.
Herefordshire perch 7 yards, therefore mile = 1·270 statute miles.
Staffordshire ,, 8 ,, ,, = 1·460 ,,
—*Ency. Brit.*, 3d edit., art. "Perch."

First we must note that the statute mile and furlong were probably independent of each other originally. The earliest mile near the statute mile was one of 5000 feet, defined as $7\frac{1}{2}$ furlongs 3 perches and 2 palms,* about 1350 AD. Then about 1470 A.D. a mile appears of 8 furlongs,* which first received legal recognition in 1593 A.D.† Now, if the mile of 8 furlongs had always existed, it is very unlikely that one containing a fractional number of furlongs would have arisen, so that it is probable that the furlong is the older measure, and that the mile was adapted to fit it. And this is also indicated by the register of Battle Abbey mentioning furlongs but not miles; so that the furlong appears a long time before the mile of 8 furlongs.

The furlong, though now defined by the yard standard, was originally independent of the present foot and yard; for it is impossible to suppose a length of $5\frac{1}{2}$ yards being selected without any reason. This is manifestly the nearest translation into the lesser standards of a measure which was originally incommensurable with them.

Thus it seems most likely (as De Morgan supposes) that the statute mile was originally 5000 feet of 12 inches, and that it was modified to 5280 feet in order to agree with the furlong, with which—as being the nearest measure in size, and the basis of land measurement—it was most required to accord. And the furlong was an independent unit, not having any exact relation to the foot of 12 inches, or the mile of 5000 feet.

Now we have seen by Gibson's maps that the long mile was evidently reckoned as 10 furlongs, being exactly $\frac{10}{8}$ of the statute mile there; and we have seen that the old mile was originally $1{\cdot}265 \pm 10$ statute miles, or even slightly less. The furlong, then, would be $\cdot 1265$ statute mile, $= 8015 \pm 64$ inches, or rather less. The chain, or $\frac{1}{10}$ of the furlong, would be $801{\cdot}5 \pm 6$ inches. Below $\frac{1}{4}$ of a chain, or a perch, we lose sight of the original subdivisions, as the link is a modern invention of land surveyors, and the $5\frac{1}{2}$ yards is merely an approximate adaptation of a different standard.

Turning now to other countries, we meet at once with a mile

* Canterbury registers, fourteenth century, quoted by De Morgan, art. "League," *Penny Cyclopædia.*

† De Morgan, in art. "Mile."

closely similar to the old English mile; this is the old French mile, which is equal to 1·21 statute miles, or within 3 per cent. of what we have seen to be probably the earliest English mile. And this resemblance is not only in length, but also in subdivision, as the French mile is 1000 toises, and this is decimally divided like the 10 furlongs in the mile, and the 10 chains in the furlong. Also, the English league consisted of two old English miles,* like the French league.

This continued decimal division of the French mile suggests that perhaps the old English mile may have had lesser subdivisions than the chain; $\frac{1}{10}$ of the chain would be 80·15 ± ·6 inches; and if this fathom was subdivided into 6 feet, like the French toise, we should have a foot of 13·36 ± ·1 inches, or rather less perhaps by the original mile.

Now, on referring to *Inductive Metrology*, p. 107, it will be seen that the commonest foot known in the mediæval remains in England is 13·22 ± ·01 inches in length; this being more commonly found even than our modern foot of 12·0 inches. Here then we have found the basis of the old mile appearing quite independently as the most frequent measure in mediæval England. This foot appears to be the same as the classical "Drusian foot," which may have been introduced by the Romans into both France and England.

The series of measures thus connected with the old English mile run thus:—

	Inches (by the mile).			Inches (by the foot).	
Foot . . .	13·36 ± ·1		or	13·22 ± ·01	
6 feet = 1 fathom .	80·15 ± ·6			79·32 ± ·06	
10 fathoms = 1 chain .	801·5 ± 6·	statute miles.		793·2 ± ·6	statute miles.
10 chains = 1 furlong	8015· ± 60·	= ·1265 ± ·001		7932· ± 6·	= ·1252 ± ·0001.
10 furlongs = 1 mile	80150· ± 600·	= 1·265 ± ·01		79320· ± 60·	= 1·252 ± ·001.

The second determination, working from the foot, which is far more accurately known than the mile, is probably the most trustworthy; and as we have observed that the original form of the mile was probably rather shorter than 1·265, therefore this restoration of the old mile from the foot, shown by various buildings, represents the data that we have as well as anything can, and is far more accurate than anything that we can hope to recover from itinerary measures.

* See Roger Bacon's distances, before quoted.

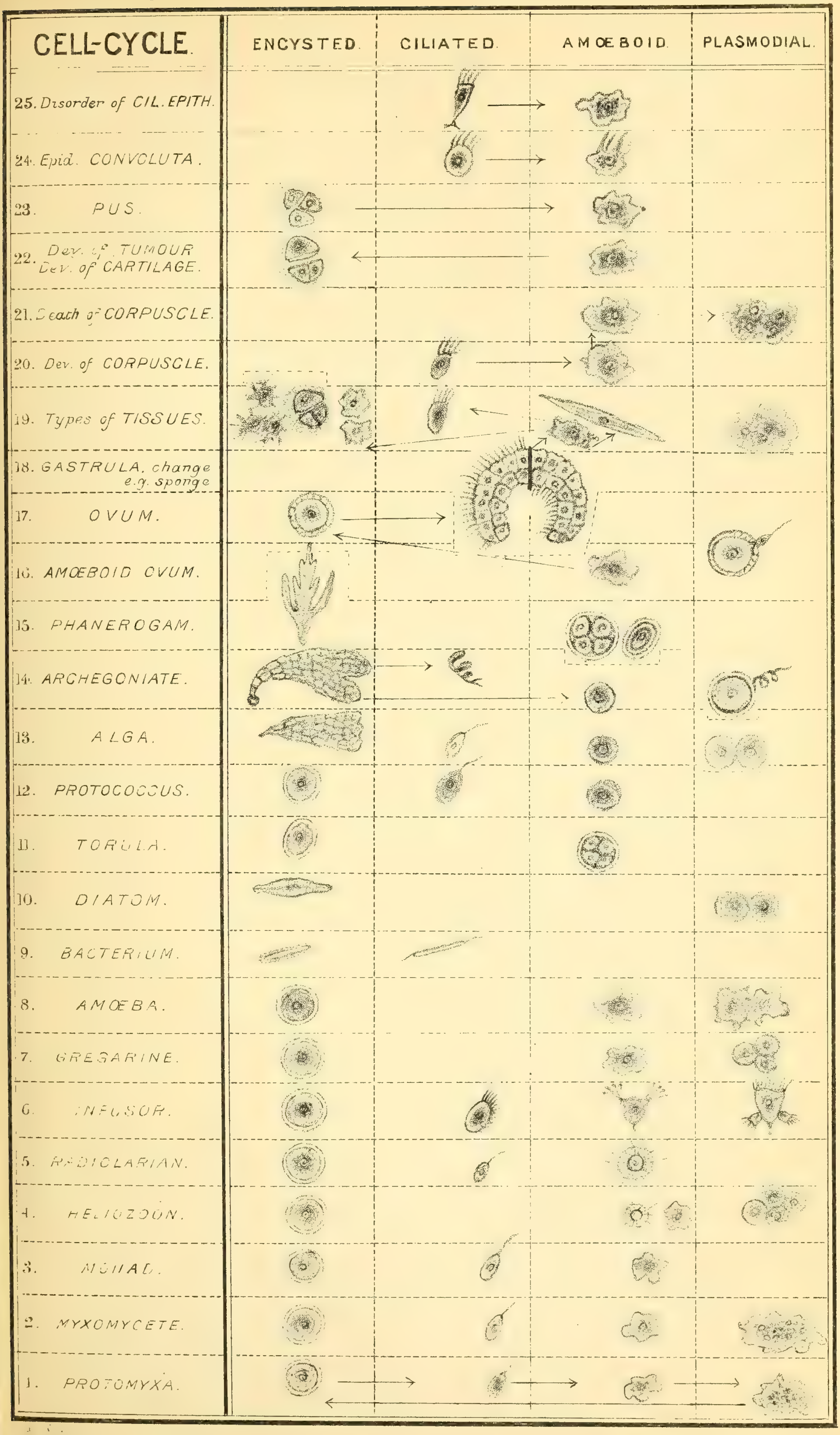
We see, then, that by the exclusive survival of the 12-inch foot, we have lost the basis of a decimal system of measures, and thus, complicated our land measure in a most troublesome manner.

In this examination, then, we have traced the old English mile back through four centuries, and seen that it varied but little in different times, and as used by different persons. And, following the analogy of the old French mile (with which it seems to have been identical), we see that it was part of the decimal system of the fathom, chain, furlong, and mile, based upon the most usual mediæval foot of England. Whether this mile was introduced by the Normans, or whether its basis had remained in England (like other measures) from Roman times, is still unsettled; and this question, as well as the local variations of the mile, and the origin of the miles of Wales and Cheshire, must remain for future discussion, when other and more complete materials may be discovered.

3. A Re-Statement of the Cell Theory, with Applications to the Morphology, Classification, and Physiology of Protists, Plants, and Animals. Together with an Hypothesis of Cell-Structure, and an Hypothesis of Contractility.* By Patrick Geddes. Plate IV.

Position and Importance of the Cell Theory in Morphology.—Vast though is the literature of vegetable and animal morphology, it becomes more readily grasped than that perhaps of any other science, when we classify it in relation to the few great works which initiated and for ever mark the successive waves of advance. Thus of the early pre-morphological or encyclopædic stage, when materials were being little more than heaped together, the works of Pliny or Gesner may be taken as types, to which the other encyclopædias of Natural History by Jonston, &c., furnish at first mere supplements. The *Systema Naturæ* of Linnæus closes the old and marks a new era, and initiates that systematic enumeration of the flora and fauna of the globe which has since made such vast progress. All subsequent systematic literature, no matter how important, no matter how much exceeding in quantity of new forms, involves no essential, no qualitative advance: thus the greater part of the proceedings of such

* Prelim. Note in *Zool. Anzeiger*, No. 146, 1883.


CELL-CYCLE.
ENCYSTED.
CILIATED.
AMŒBOID.
PLASMODIAL.
25. Disorder of CIL. EPITH.
24. Epid. CONVOLUTA.
23. PUS.
22. Dev. of TUMOUR
Dev. of CARTILAGE.
21. Death of CORPUSCLE.
20. Dev. of CORPUSCLE.
19. Types of TISSUES.
18. GASTRULA, change
e.g. sponge
17. OVUM.
16. AMŒBOID OVUM.
15. PHANEROGAM.
14. ARCHEGONIATE.
13. ALGA.
12. PROTOCOCCUS.
11. TORULA.
10. DIATOM.
9. BACTERIUM.
8. AMŒBA.
7. GREGARINE.
6. INFUSOR.
5. RADIOLARIAN.
4. HELIOZOON.
3. MONAD.
2. MYXOMYCETE.
1. PROTOMYXA.

Societies as the Zoological or the Linnean, such new and important faunistic literature as that contained in the magnificent volumes of the "Challenger" Expedition, or even the greatest systematic works, find their highest place not as superseding, but as supplementing the fundamental classic of Linnæus. Similarly all works of detailed anatomical research united with exact comparison and clear generalisation, are in botany simply to be regarded as supplementary to the little work in which Antoine de Jussieu founded the Natural System, or in zoology to the *Règne Animal* of Cuvier, himself also an intellectual heir of Vesalius. Embryological literature in like manner finds its place in the appendix and commentary to the works of Robert Brown or Von Baer respectively; at the head of all investigations of serial homologies stands Goethe's memorable essay *On the Metamorphoses of Plants;* while all evolutionary literature may be arranged round the works of Lamarck and Darwin. The morphological investigator, unless claiming to initiate some new line of thought, has thus to take his place simply as an assistant to one or more of a few immortal masters.

But the cell theory? This is apt to be excluded from general morphology altogether, and to have a separate subordinate province —of histology—erected for it, a vicious tendency, which although by no means fully adopted, still somewhat injures the continuity of treatment in the writer's recent essay on Morphology.* To ascertain its position, we must first briefly glance at its history.

Here the fundamental classic is undoubtedly the *Anatomie Générale* of Bichât, though in this the name of cell does not even occur, the "tissue" being assumed as fundamental. The analysis of the organism into definite structural components is, however, the main idea; after this the history of histology is little more than of accumulating observations with improving optical and technical appliances, until we come to Schleiden, who boldly referred all vegetable tissues to the cellular type, and the plant embryo to a single nucleated cell; while Schwann, by immediately extending the generalisation to the animal world, fully constituted the cell theory. This idea then is fundamental in morphology; for the innumerable species and genera of plants and animals made known under the leadership

* *Ency. Brit.*, xvi. p. 837; amended in German translation, *Jenaische Zeitschr.*, 1884.

of Linnæus, and the numberless anatomical resemblances and differences investigated by Cuvier and his disciples, become reduced to resemblances and differences in the details of structure and position of fundamentally similar unit masses; while the resemblances of development made known by embryologists become the connecting link between the cell theory and these generalisations of adult structure. It is not necessary to do more than merely allude to such applications of the cell theory, or to that of the study of pathological structure initiated by Goodsir and Virchow, or to that brilliant confirmation of the unity of the animal and vegetable cell which has lately been afforded by the detailed study of the processes of cell multiplication. Agassiz* was fully justified in the opinion that the most brilliant result of modern science was the ovum-theory, and thus it is beyond dispute that "in our own day, as in those of Bichât and Schwann, the labours of the histologist, when inspired by higher aims than that of the mere multiplication of descriptive detail, are of supreme morphological importance, and result in the demonstration of a unity of organic structure deeper even than any which we owe to Linnæus or Cuvier, Goethe or Geoffroy." †

Cell.—The position and importance of the cell theory being thus defined, the fundamental necessity for a precise conception of the cell itself will be sufficiently obvious. The early progress of this is well known; at first the vegetable cell-wall gave the type, while Schwann's cells were essentially nucleated vesicles with fluid contents. Dujardin described the "sarcode" of Foraminifera; Von Mohl discovered the "protoplasm" of the vegetable cell; while Max Schultze identified both as the same substance; showed it, and not the membrane to be essential; and gave an amended definition of the cell as a unit mass of nucleated protoplasm. For working purposes it is this conception which is generally accepted, and almost every dissertation or treatise upon the general questions of botany or zoology, histology or physiology, commences by postulating it, the amœba being most frequently taken as the standard type. ‡

Unsolved Problems.—Such a conception of the fundamental

* *Essay on Classification.*

† "Morphology," *Ency. Brit.*, xvi. sec. 3, p. 840.

‡ Of this no better instance can be afforded than the introduction to the admirable *Manual of Physiology* of Dr Michael Foster.

cellular unit, however valuable, yet throws no light upon a large number of problems at present under dispute; and it is the aim of the present paper to draw attention to some of these, and by the aid of a re-statement of the cell theory (a new appendix as it were to the *Anatomie Générale*, or to the work of Schwann), to propose a solution of them.

The problems then which it is proposed to discuss may be briefly enumerated for convenience under separate heads, as follows:—

(1) The classification and affinities of the Protozoa.

(2) The classification and affinities of the Protophytes.

(3) The systematic position of the Myxomycetes and other peculiar forms.

(4) The acceptance or rejection of Hæckel's third intermediate sub-kingdom *Protista.*

(5) The phylogeny of the lower plants and animals, and their origin from one or several stocks.

(6) The relation of the Protophytes to the higher plants.

(7) The relation of the Protozoa to the higher animals.

(8) The morphological relations of plants to animals and their origin from a common stock, or from separate ones.

(9) The classification of animal tissues.

(10) The physiological rationale of changes of cell-form.

(11) A theory of the origin of sexual reproduction, and its relation to conjugation and other cases of cell union.

(12) The relation between normal and pathological tissues.

(13) The influence of the environment on the origin of organic forms.

(14) A theory of cellular variation (since the theory of descent involves a theory of variation, and all variations, normal and pathological alike) must ultimately be expressible in terms of cellular ones.

1. *Classification and Affinities of the Protozoa.*—The Protozoa have long been thrown into a few main groups, of which the *Rhizopoda*, embracing all essentially amœboid forms like the Protoplasta, Foraminifera, Heliozoa, and Radiolaria, and the Infusoria, including all those of permanent and usually ciliated type, are the oldest and most important. The position of the Gregarinida, of the Monads, and still more of forms like *Chlamydomyxa* and the Labyrinthulida,

or Hæckel's *Protomyxa*, is still disputed, nor is that of Rhizopods to Infusors, despite their more or less intermediate forms, as yet settled.

But our current conceptions of the groups of Protista are based upon their more prominent and permanent characters only. An infusorian is constantly thought of as a permanently ciliated or flagellate organism; a radiolarian is constantly described as a highly differentiated rhizopod, with two layers of protoplasm, a gelatinous envelope, yellow cells, and siliceous skeleton; or again its simpler ally the heliozoon is seldom or never thought of without its radiating pseudopodia with their peculiar axial filaments.

Yet such conceptions involve a morphological fallacy of the most serious kind. These are indeed the most highly differentiated, the most frequent, the most permanent, and therefore the most striking forms in which these organisms are known to us, but of late years it has been becoming more and more obvious that each of these well-known forms is at best but the most important stage of a life-history, during which the organism passes through one or more other phases of form, which may indeed be transitory, but thereby lose no whit of their morphological distinctness or importance.

Thus, thanks to the researches of Dallinger and Drysdale, Butschli, Savile Kent, and others,* we know that a monad is not a permanently flagellate form, but appears at one time encysted, at another becomes amœboid; the ciliated embryos of the Acinetæ have long been known,† while more recent investigations have established the multiplication of radiolarians by zoopores,‡ or the frequent union of several individuals of various species of Heliozoa§ or of Gregarines|| into a single mass. In short, the progress of recent research among these forms has largely lain in revealing the existence in even the most highly differentiated forms of a life-cycle of several distinct phases.

In lower forms more attention is paid to the whole life-cycle, yet not sufficiently so. The Amœba is still constantly spoken of as if its encysted stage were of no morphological interest, whereas no permanently amœboid form has ever been proved by continuous

* Savile Kent, *Manual of the Infusoria*. † *Ibid.*

‡ Brandt, *Monatsb. d. Berlin Akad.*, 1881.

§ Gruber, *Zool. Anzeiger*, No. 118, 1882.

|| Gabriel, "Z. Classif. d. Gregarinen," *Zool. Anzeiger*, 1880.

observation to exist; in the Gregarine, on the other hand, the amœboid state is often practically ignored by classifiers.

In the remarkable Protomyxa of Hæckel, however, we have an organism in which several phases of form are almost equally prominent, so that its description as an amœboid, or a ciliated or as an encysted organism, has been alike impossible. For here is no permanent highly differentiated form; but an eventful life-history in which one protean mass of protoplasm passes through a cycle of several distinct phases. Let us carefully examine then these phases, since light may thus be thrown upon the life-histories of the higher Protozoa already referred to.

Starting then from the encysted stage, in which a mass of protoplasm is surrounded by a dense envelope, we find that from this after a time (in which division of the protoplasm has in this case occurred), there issues a swarm of somewhat pear-shaped, naked, motile, flagellate organisms. After a brief period of active locomotion, these lose their flagellum and their permanent form alike, extrude pseudopodia, in short, melt down into amœbæ. After some period of amœboid life they flow together into a single protoplasmic mass—unite into a plasmodium, as it is termed, and this after another brief but remarkable period of locomotion and pseudopodial activity, settles down into a spheroidal mass; this re-encysts itself, and the whole cycle commences anew (Plate IV. fig. 1).

If now we make a diagrammatic representation of this life-history (or rather *form-history*, as it should more accurately be termed), of *Protomyxa*, exhibiting (1) the encysted, (2) the ciliated, (3) the amœboid, and (4) the plasmodial stages, we shall find that all those temporary phases of form observed among the higher Protozoa may at once be referred to one or other of these (figs. 3, 8). If this be so, those curious phenomena of the exhibition of ciliated forms by organisms usually of amœboid type like the Radiolarians, or of amœboid forms by organisms almost permanently encysted or motile, like Gregarines or Monads respectively, lose their anomaly, and come under a generalisation at once simple and comprehensive, viz., that a form-history essentially similar to that of *Protomyxa* (with blanks it is true, but blanks which the progress of discovery is constantly filling up, and may not unlikely almost wholly fill), may be sketched out for all the higher Protozoa. The same idea

may be better expressed in the statement that the higher Protozoa may be regarded as organisms of fundamentally Protomyxoid form-history, in which, however, some one phase has attained comparatively high specialisation and differentiation, together with relatively greater permanence. Or the same idea may be stated in the exactly converse way, that the Protozoa may be viewed as organisms of fundamentally Protomyxoid form-history, in which, however, one, two, or three of the phases become abbreviated into merely embryonic ones, or may even (by that shortening of development with which embryologists are so familiar in the higher organism) become completely suppressed.

Thus then, if illustration be needed, a Heliozoon differs from Protomyxa merely * in the higher differentiation and relative permanence of the amœboid phase of its life-cycle, since more or less brief encysted, ciliated, and plasmodial phases have all been observed. The more specialised but kindred Radiolarian seems to have lost its plasmodial phase; so too, perhaps, has the monad, while in the Gregarine only the ciliated state is wanting.

2. *Affinities of the Protophyta.*—Passing now to the second problem proposed at the outset, that of the affinities of the Protophytes, the same conception may be at once applied. Too much importance is here attached to the encysted phase, for the life-cycle is clearly apparent in many forms. Treviranus, in 1811, made the notable discovery that the spores of Confervæ move like Infusoria.† Many years later Unger described the same phenomena in *Vaucheria clavata*, as "the plant in the moment of transition to the animal,"‡ while Von Siebold and others argued against this essentially just view, with more ingenuity than soundness. The wide prevalence of this change is constantly being confirmed. Not only have we a thoroughly well-defined and constant cycle between the resting and the ciliated state, but we may fairly reckon the brief phase of inactivity, which so often is observable between the loss of cilia and the return to the encysted state (when the organism closely resembles

* The possession or non-possession of a nucleus is of course immaterial, so far as the form-history is concerned.

† Treviranus, *Beitr. z. Pfl. Physiol.*, Gött. 1811, p. 78.

‡ Unger, *Die Pflanze in Momente d. Thierwendung*, Wien, 1843. Siebold, *Dissert. de finibus int. reg. an. et reg. constit.*, Erlangen, 1844.

a contracted amœba), as representing the amœboid form. A distinct assumption of the amœboid state at the close of the ciliated one, is sometimes to be observed,—as lately by Reinke* in Bangia. And thus the cycle is complete, save only for the plasmodial phase.

The importance of this view for the Protophytes then, is scarcely less than for the Protozoa. With a tendency of the encysted state to predominance, more marked even than in the Gregarines, the other phases are by no means obliterated, and we thus—and only thus—obtain an intelligible explanation of that alternation between the resting and the motile phase which is so frequent and so characteristic. The inevitable applicability of this to classification, and the light it yields, will be sufficiently obvious. Without prematurely proposing a detailed classification, it will be obvious that we must regard those forms, which like *Torula*, exhibit only the resting state, not as primitive, but as exceedingly specialised, and those which exhibit more and more of the cycle as less so.

3. *Affinities of the Myxomycetes.*—Passing to the *Myxomycetes*, it will at once be evident, that unless the present theory can be entirely overturned, they have no place among the fungi proper—where it is the encysted phase that predominates, the others being greatly reduced or suppressed; but are in fact morphologically as remote from these as are the monads. The Myxomycetes must be placed next *Protomyxa*; in fact, *Protomyxa* is simply the least differentiated known Myxomycete. Their higher forms are interesting—first, in very frequently showing less of the ciliated stage, and secondly (a more important character, since here they are unique among living beings), in affording an enormous differentiation of their plasmodial stage; the complicated forms which many of them exhibit being simply those of their plasmodial froth, to which permanent shape is then given by the formation of a cellulose envelope. The resemblance to fungi is thus as purely superficial and adaptive as that, for instance, of Hydroids to Polyzoa, and, like it, is of physiological interest alone.

4. *The "Protista."*—The general non-adoption of Hæckel's proposal of a third intermediate *Regnum Protisticum*, has been due to three main reasons,—of which the first is that the proposal seems only to double the difficulty, since it does not enable us to distinguish

* *Mittheil. d. Zool. Stat. in Neapel.*, 1883.

Protista from animals on the one hand, or plants on the other; the second, closely related to the first, that Protista are too heterogeneous, and do not admit of exact definition; but the third and most potent reason has, however, simply been that excessive specialisation which allows most otherwise competent students of the Protozoa to remain in entire indifference to the Protophytes, and the even more general and deplorable ignorance of the Protozoa which prevails among microscopic botanists.

The present theory, however, does away with the apparent heterogeneity of the Protista. On the view that Protozoa and Protophytes alike exhibit more or less specialised and abbreviated forms of a common life-cycle, the thirteen groups of Hæckel* are seen to be but forms of one, and there remains absolutely no morphological reason for their continued separation (nor for that matter, any physiological reason either, were such considerations, irrelevant as they are to morphological taxonomy, any longer admissible). Nor is the objection of Huxley really valid. The limit between *Protista* and *Animalia* remains simply that between Protozoa and Metazoa; and that between Protozoa and Protophytes being given up, there remains no more difficulty of separating the higher plants than there was before—a difficulty which, however undoubted, is not increased by uniting the lower forms.

The thorough unity and naturalness of the Protista being thus obvious, they naturally fall into a series corresponding to the stages of the life-cycle. In the Schizomycetes and the Palmellaceæ the resting and motile stages are almost equally prominent, while in Gregarines, and still more in Desmids and Diatoms, and especially Saccharomycetes, the encysted stage predominates. The Protoplasta, Foraminifera, Heliozoa, and Radiolaria represent of course the predominatingly rhizopod or amœboid stage, while the Infusoria represent the ciliated, and the Myxomycetes, as has been said, the plasmodial.

It may at first sight seem as if the old grouping of Protophytes and Protozoa were not seriously modified, since the Protophyta always essentially corresponded to the series of generally encysted forms. And so far true; the encysted series may still be termed Protophytes without any serious harm. But it must be clearly

* *Die Protisten.*

observed that there remains not *one* morphological type merely, to be discriminated as Protozoa, but *three*—the ciliated, amœboid, and plasmodial,—all, indeed, physiologically analogous in exhibiting movements (a phenomenon of which pure morphology takes absolutely no cognizance), but as distinct in form from each other as from the encysted form. The utter confusion which has too long maintained as to the distinction of plant and animal life is thus seen to be due to the want of that discrimination of morphological from physiological considerations, which is now happily nearly complete in the study of higher organisms. In short, though the encysted and usually non-motile cells or cell-aggregates may be conveniently termed plants by the physiologist, and though usually non-encysted and motile cells or cell-aggregates may similarly be grouped as animals,—yet the morphologist, distinguishing form-history from life-history, must recognise among the Protista four main lines of differentiation, or four series, which may perhaps conveniently be termed *Protophyta*, *Rhizopoda*, *Ciliales*, and *Plasmodiales*. (See Plate IV. figs. 1–13 in first series.)

5. *Phylogeny of Protista.*—On this view also there is no necessity for the assumption lately coming into view of the origin of the Protista from several distinct stocks, or for accepting, with Bergh,* so specialised a form as *Peridinium* as a type of the primeval Protozoon, for all are naturally derivable from a simple Myxomycete or Protomyxoid ancestor. Of course, this view by no means excludes the possibility of the remoter and simpler Protamœboid progenitor assumed by Hæckel.

6. *Relation of the Protophytes to the Higher Plants.*—Transverse division may of course occur in the encysted, amœboid, or ciliated stage of the life-cycle of a cell. When this takes place chiefly in the encysted state the tough and coherent wall holds the resultant cell-aggregate together; this cell-aggregate soon becomes moulded by the force of the environment into some definite form; and what we term a vegetable organism (a Metaphyte corresponding to a Metazoon) is the result.

But the cells of our multicellular plant do not lose their tendency to cycle. Alike in linear, superficial, or solid aggregates, the cycle is

* Bergh, "D. Org. d. Cilio-flagellata," *Morph. Jahrb.* vii. 2; Abstract by T. J. Parker, *N. Z. Jour. of Sci.*, October 1882.

plainly seen: and it is scarcely necessary to remind the reader of the zoospores of a confervoid Alga, or of the similar mode of reproduction of an *Ulva.* It may be objected that here only two stages of the cycle are present; but a third, the amœboid, not uncommonly occurs, for that the brief quiescent state of the zoospore before re-encystment may fairly be considered amœboid, is demonstrated by such observations as those of Reinke,* who has lately figured a true amœboid stage in the settling zoospore of *Bangia.*

In Fucus, again, the ovum-cell has rejuvenesced, in other words has gone through an amœboid stage, while other cells rejuvenesce as antherozoids into the ciliated phase. In the terrestrial Archegoniata, too, we have the same phenomena; even in the Phanerogams, condemned as all their cells seem to perpetual incarceration, there remains one fleeting and imperfect recapitulation of the cellular life-cycle in the embryonic rejuvenescence of the pollen grain and ovum cell (see fig. 15).

7. *Relation of Protozoa to Higher Animals.*—If transverse division occur in the ciliated state, the new cells must necessarily almost invariably separate, must row apart, and thus it is natural that only comparatively few and transitory cases of ciliated aggregates are known. In the amœboid state, however, the aggregate produced by division remains much more readily in continuity, and it would thus seem much more probable that the Metazoa should originate from Protista in which the amœboid stage was somewhat more permanent and more subject to division, than from the ciliated forms, as has sometimes been suggested, particularly for the sponges.

8. *Common or separate Descent and Affinities of Animalia and Vegetabilia.*—If the preceding facts and deductions be accepted, it need only be briefly pointed out, that the affinities of plants and animals are far closer than botanists and zoologists are generally accustomed to assume, since both are descended from a Protomyxoid ancestor, and may, in fact, from our present point of view, be described not merely, as the common phrase goes, as amœboid or encysted cell-aggregates, but as aggregates of Protomyxomycetes, variously grouped and arranged indeed, but never so highly specialised as to lose all traces of their individual ancestral life-cycle. The notion of *three* kingdoms of nature—animal, vegetable, and

* *Op. cit.*

mineral—"that disastrous philosophic and scientific aberration" bequeathed by the alchemists to the last encyclopædist of Gesner's school, and unfortunately adopted and sanctioned by Linnæus, has not of course been seriously adopted by any philosophical biologist of the century; hardly the narrowest specialist among zoologists or botanists any longer seriously doubts the validity of the classification of natural objects into two groups only—inorganic and organic—yet, at the same time, the vicious results of the earlier dogma still everywhere survive, and indeed necessarily so. For the unity of plant and animal life requires morphological demonstration, and that more precise than has hitherto been afforded by merely separating off the lowest plants and animals into a third still heterogeneous group of *Protista.* This deficiency is supplied by the present argument, for if the Protista, the Vegetabilia and the Animalia have indeed been correctly interpreted, as somewhat variously specialised cell-aggregates derived from an ancestral Protomyxomycete, their consolidation into a single kingdom is a matter of course. In one edition of the *Systema Naturæ,* Linnæus clearly recognised the fundamental unity of plants and animals, by uniting them in opposition to the non-living world (*Conserta*) as *Organisata,* and this term it is accordingly not only convenient, but necessary forthwith to revive.

9. *Morphological Classification of Animal Tissues.*—Histologists are accustomed to recognise three main groups of animal tissues. Thus Cornil and Ranvier* distinguish (1) connective tissues, in which the cells are united and separated by a substance of characteristic form and properties; (2) muscular and nervous tissue, in which the cells have undergone extraordinary modifications, both structural and functional; (3) epithelial tissue, in which the cells possess a regular and constant evolution.

In this classification, however, as in so many others, morphological and physiological characters are not kept distinct. In briefly glancing at morphological characters only, it is evident we may best approach the problem by first noticing some of those cellular transformations made known by the recent students of embryology. Histogenesis must underlie histology.

An ovum is at first a naked amœboid cell, then assumes the encysted state, then segments into an aggregate of amœboid cells; this

* *Manuel d'Histologie Pathologique,* i. p. 11, Paris, 1881.

becomes perhaps a ciliated morula, this again a gastrula, with ciliated ectoderm and amœboid endoderm; this may settle down as in sponges, its cells re-cycling anew, the ectodermic layer becoming amœboid, the endodermic ciliated (fig. 18). The endodermic cells remain permanently more or less amœboid, as the recently much investigated phenomena of intercellular digestion have so clearly established. The amœboid ectodermic cells, on the other hand, may give rise to muscle—and a muscle is but an amœba elongated so as permanently to contract along one line; on the other hand, they may pass into a quiescent state, or throw out encysting material, which may either enclose them individually, as in Ascidians, or form a collective external envelope, as in Arthropods. The mesodermic cells may either remain unspecialised as amœboid corpuscles, may specialise as muscular tissue, or cycle into the resting state, *i.e.*, develop into connective tissue (see fig. 19).

And if the cell cycle persist thus long in the life-history of the organisms, why should it disappear? In reality, it does not disappear completely. The amœboid corpuscles of the perivisceral fluid of an invertebrate—say an Echinus—develop, largely at least, from the ciliated epithelium lining of the cœlome—permanently exhibit, that is to say, one of the most characteristic phenomena of the cycle. And when under proper precautions we examine a fresh drop of the fluid, we observe the corpuscles as they die running together into a plasmodium,* so perfectly similar to that of a Myxomycete as actually to have been described by a recent observer as a new genus and species.† And this phase of the cycle takes place, in the so-called coagulation of corpusculate fluids of invertebrates generally.‡ Numerous other instances of the occurrence of some phase of the cell-cycle have been recorded, and have already been collected by the writer in a series of papers which have led to the present one; it is unnecessary to call attention to others, save perhaps the especially interesting announcement by Professor Haddon,§ of the occurrence of a plasmodial union of cells during the normal histolysis of Polyzoa.

* Geddes, "Observations s. l. fluide périvisceral des Oursins," *Arch. Zool. Exp.* VIII.

† *Comptes Rendus*, t. lxxxii. No. 21.

‡ Geddes, "On the Coag. of Amœb. Cells into Plasmodia," &c., *Proc. Roy. Soc. Lond.*, No. 202, 1880, and *Trans. Roy. Phys. Soc. Edin.*, 1882.

§ Haddon, "On Budding in Polyzoa," *Quart. Jour. Micros. Sci.*, 1883.

Thus then it will be sufficiently evident that the morphological classification of tissues must be based upon the cell-cycle, the various permanent tissues being viewed as specialisations of one or other of its fundamental forms, or perhaps sometimes as synthetic types between them. And, finally, compressing the gist of several possible papers into as many passing allusions, it is evident that the theory affords us a basis for the criticism and compression of the recent literature—(1) of intercellular digestion (natural to the amœboid phase); (2) of that long dispute respecting the origin of the sexual elements of *Hydrozoa,* from ectoderm to endoderm (the cells of both of which show the cycle, and either layer thus develop ova or spermatozoa); (3) of the cœlome theory.

10. *Physiological Rationale of the Cell-Cycle.*—It is now time to demand some physiological rationale for this cycle, which has been hitherto regarded as of morphological interest alone. A mass of protoplasm anywhere is under constantly varying conditions—at one time receiving abundant energy from the environment, at another little or none. These variations are at least of three main kinds—(1) temperature, (2) light, (3) food. Thus, then a rhythm of more or less vital activity in definite relation to these conditions of the environment is inevitable.

It is unnecessary to remind the histological reader how often and how easily the existence of this rhythm is verified by actual observation. Every student is shown the intensification of amœboid or ciliary movement by heat, and its depression by cold or electric shock, and knows too the influences of various reagents or gases (*i.e.*, of modification of *food* in the general sense) in stimulating or retarding activity. The dependence on climate of the cell-cycle of the lower organisms, *e.g.*, *Protococcus* or *Amœba,* is familiar to every microscopist. The amœboid state varies widely with food and temperature; while the actual transition from the ciliated stage to the amœboid, and conversely, have been repeatedly observed; witness the papers of Hæckel, Lankester, and others including the writer.* They can only be viewed in fact as distinct from the morphological point of view; physiologically, they show but the extremes of one motile state.

* "On the Morphology and Physiol. of the Cell," *Trans. Roy. Phys. Soc. Edin.*, 1882.

Vast importance has been attached to the cellulose wall, as an assumed characteristic of plants, yet not only the cyst of a Myxomycete, but that of an Amœba, is now known to consist of cellulose. How is this cellulose wall to be accounted for? Why should the resting phase possess a cyst? What is the physiological rationale of this morphological characteristic of the resting phase?

Contracting muscle evolves carbonic acid and water, with evolution of heat; the quantity of heat and water products evolved diminishes as contractile activity diminishes; and this physiological common-place must hold true of every contracting cell, ciliated or amœboid. But contractility implies waste of formed materials, diminution of contractility therefore implies diminution of this disintegration of matter and dissipation of energy, of this combustion which we term waste. Cessation of contractility, therefore, involves cessation of the combustion of some product—of some fuel which was formerly required to maintain the process. *The cellulose wall which appears on the assumption of the quiescent state is thus the equivalent of the carbonic acid and water which were being formed and excreted during the state of contraction.* Being no longer required as fuel, it becomes itself thrown out as a waste product—which simply by reason of its chemical and physical properties—its insolubility and coherence—acquires at once its morphological permanence and its protective use.*

The applicability of this physiological conception to a new series of problems can here only be briefly hinted at. Without more than mentioning the discovery of Durin as to the formation of cellulose from cane sugar,† it may be briefly pointed out (1) that the occurrence of cellulose in Ascidians, or in pathological cases in the human brain, &c., is by no means unintelligible—the difficulty is rather the reverse—to explain why it is not invariably present in resting cells. These are never destitute of external intercellular substance, and the

* A vivid confirmation of the preceding theory of the origin of the cellulose wall has been suggested to me since the reading of this paper by my friend Dr Milne Murray, who reminds me that a quiescent muscle, instead of evolving carbonic acid and water, produces an enormous store of muscle-sugar or inosite, and that this is an isomer of cellulose, $C_6H_{10}O_5$. The same conception may throw light upon the physiological chemistry of other carbohydrates, such as glycogen, starch, &c.

† *Ann. Sci. Nat. Bot.*, 1877.

hypothesis thrown out many years ago by M. Frémy, our leading authority upon the chemistry of cellulose—that chitin and other analogous bodies really consist of cellulose linked with a proteid, seems well worth reviving. On this point the researches of Krukenberg,* especially are promising light.†

11. *Origin of the process of Sexual Reproduction.*—The plasmodial stage which terminates the cycle, seems in the first place little more than a mere mechanical union of cells exhausted by prolonged activity; in all normal cases it is soon followed by prolonged repose in the encysted state, and in the experiment upon invertebrate corpuscles, by quiescence and death. In the plasmodia of Protomyxa, Myxomycetes, and of invertebrate corpuscles alike, notably Echinus, the union is followed by a brief but extraordinary intensification of amœboid activity‡—the cause of which, as passing from cellular to protoplasmic physiology, must be discussed in a subsequent paper.

Some years ago considerable weight was attached by Sachs§ to the hypothesis that the plasmodium formation of Myxomycetes might be regarded as a process of multiple conjugation. This view he now, however, withdraws,|| mainly on the ground that the nuclei have been shown not to coalesce as in true conjugation. It appears to me, however, that on the present theory the revival of that hypothesis, though in a somewhat different form, is inevitable.

No one doubts that the sexual elements of plants and animals are represented by the very slightly differentiated conjugating cells of *Spirogyra*, or the almost undifferentiated cells of *Mesocarpus*. With these the conjugation of two Amœbæ, two Actinosphæria or two Gregarines, are classified as a matter of course. But the recent observations of Gabriel upon the multiple conjugation of Actinosphæria, or of Gruber upon that of Gregarines, leave no doubt that in these cases at least conjugation may be multiple. The only difficulty is that offered by the non-coalescence of the nuclei. But even if there were any certain grounds for supposing that the essence of the process lies in the union of the nuclei, rather than in

* Krukenberg, *Vergleich. Physiol. Studien*, Bd. ii.

† *Ann. Sci. Nat. Bot.*, 1877.

‡ See figure of plasmodium of Echinus in author's papers in *Arch. Zool. Exp.* VIII.; *Proc. Roy. Soc. Lond.*, 1880, or *Trans. Roy. Phys. Soc. Edin.*, 1882.

§ *Manual of Botany*, 1st Eng. ed.

|| *Ibid.*, 2nd ed., Appendix.

the union of the protoplasm, we must expect on the evolution theory an incipient stage in which only the latter phenomenon should occur. That the nucleus is not invariable, much less indispensable, is of course evidenced by the existence of the Monera, or if their distinctness be questioned, we may appeal to the recent demonstration, apparently by the most refined histological appliances, that in young *Actinophrys* a nucleus is really absent,* and develops independently in adult life. Moreover, on the present view of the almost primordial nature of the Myxomycetes, their plasmodium is the only phenomenon which at all resembles conjugation, and since we have already viewed amœboid, ciliated, and resting forms as specialisations of the corresponding phases, it is no great extension of the theory to view conjugation as specialised from the plasmodial phase. This view will be strengthened when in the next paper we leave the cell-cycle to consider the physiological processes in the protoplasm itself.

12. *Relation between Normal and Pathological Tissues.*—Unless the step taken by Goodsir and Virchow—of regarding all pathological variations as ultimately expressible in terms of cellular structure and function, *i.e.*, of the cell theory, be deliberately retraced, we cannot avoid the application of the present re-statement of the cell theory to pathology. To do this in detail would, of course, require far more than the writer's knowledge, but a few brief and tentative suggestions may be put forward. Pathologists are reducing tumours to a common type—which seems essentially that of cell multiplication in the resting or encysted stage. It is certainly more easy to suppose, on the present view, that the appearance of a connective tissue tumour has been due to the placing of ordinary cells in new conditions favourable to the assumption of that phase of the ancestral cycle; or from a slightly different point of view, to say that that inhibition of the cycle essential to the permanence of the whole organism has been locally removed, than, for instance, to suppose, with Cohnheim, the existence of a long dormant mass of embryonic tissue.

Again, we can easily modify the environment of living cells under the microscope—we can accelerate or diminish the activities of ciliated epithelium, by heat and cold, oxygen and carbonic acid, by alkali and chloroform. I have elsewhere † pointed out that the

* Gruber, *Zool. Anzeiger*, No. 118, 1882.

† *Op. cit.*, *Proc. Roy. Soc. Lond.*, 1879.

solution of the old dispute, as to whether the integument of certain planarians was amœboid or ciliated, was afforded by specimens of *Convoluta* which had been kept for many days in a shallow aquarium, scantily protected at nights from the cold of a severe winter. The normally ciliated cells of the ectoderm could be watched in actual progress of collapse into the amœboid state, and their cilia figured during their passage into pseudopodia (fig. 24). Here was a definite pathological change, in approximately known conditions, and distinctly in terms of the cell-cycle. Why should not a disorder of the ciliated epithelium of the bronchial passages be at least partly susceptible of essentially the same explanation? (fig. 25). May not the formation of pus be partly interpreted in terms of degeneration to the amœboid stage, and may not inflammatory changes be regarded as temporary and excessive intensifications of cellular activity, indicating a tendency to reversion to the amœboid state?

Whether these particular instances be acceptable to professed pathologists or not is after all a minor consideration, their aim has been merely to suggest that the phenomena of the cell-cycle—and particularly of those changes occurring under definite experimental conditions—may be applicable in their hands to fruitful research, not only in pathological histology, but in cellular physiology and therapeutics.*

Its adaptability to the treatment of physiological speculations is also obvious. Since the activities of the body are the aggregate activities of its component cells, not merely such phenomena as those of varying ciliary activity, but those of fatigue and sleep, of muscular and nervous tonus, and in fact every rhythm of increasing and decreasing cellular activity, become intelligible when viewed from this most highly generalised standpoint of physiology, as specialisations of that primeval cellular rhythm which lies before us in this life-history of the Protomyxomycete.

13. *Influence of the Environment upon the origin of Plants and Animals.*—One further physiological consideration may be briefly indicated, from its bearing on general morphology. The cell-cycle in its entirety is only possible in a fluid medium. Without water cilia cannot play, without fluid the amœba and the plasmodium must

* This conception is somewhat developed in the subsequent paper.

alike become stationary, and either dry up or encyst themselves. The cell-cycle in plants therefore is only found in its entirety in algæ. Archegoniates are indeed terrestrial, but their brief cell-cycle during fertilisation is absolutely dependent upon the abundant moisture, without access to which neither moss, liverwort, nor prothallium ever occurs. Thus it is that the higher terrestrial plants have become restricted to the encysted phase. Only to escape death, has the dryad become thus shut up within the tree; but once so protected the extensive replacement of the cryptogams by the phanerogams, in all the less humid climates of the world, is readily accounted for.

Passing to animal life, the vast preponderance of aquatic forms over terrestrial, is very similarly to be accounted for by the aid of the present theory. Only the higher members of a few groups have successfully emerged from their native element, and their existence depends upon their differentiation of an internal fluid medium, of that "milieu intérieur" upon which Claude Bernard was wont to lay such stress,* this in turn depending upon the early differentiation of internal cavities. The interdependence of morphological and physiological theory will be sufficiently obvious from such considerations.†

14. *Theory of Variation.*—The more completely one accepts and reflects upon the theory of natural selection, the more one feels the necessity for some view more satisfactory than heretofore of the causes of variation.‡ The present conception of the cell-cycle seems to go far towards supplying this. On the ordinary conception of the cell theory, that of the plant as an aggregate of encysted cells, and of the animal as an aggregate of essentially amœboid ones, the organism cannot be credited with any innate variability—its observed variations are merely those which it receives, so to speak, between hammer and anvil—from the forces of the environment. The present conception, however, of all cells, however varied and specialised, being essentially differentiations from an encysted, an amœboid or a ciliated form, and of these forms as phases of a single form-history, enables us to credit the cells and the resultant organism with an innate tendency to variation, and this along

* *Phénomènes de la vie communs aux an. et aux vég.*, Paris, 1879.
† "Morphology," *Ency. Brit.*, 'Rel. of Morphol. to Physiol.'
‡ *Cf. Origin of Species.*

certain definite and investigable lines. These modifications would still of course be largely determined by modification in the environment, yet the change of view is considerable. On the former view the organism is a plastic but essentially inert mass, yielding passively to the forces of the environment; on the latter, it is an active community, of which some or many members, under the influence of any favourable change of conditions, or the removal of any restraints, external or internal, immediately press into other positions and functions, which however apparently new, are either specialisations of the existing, or reversions to an earlier type.

Variation and disease are thus most closely akin; for since all variations are ultimately cellular, pathological changes are simply definable as those variations which happen not to be conducive to success in the struggle for existence. And thus we might proceed further and further with the discussion of ætiology.

The preceding theory then, although its range of application, unlimited in the scale of organic nature, may at first sight alarm the specialist, is actually founded on a simple but solid basis of observed facts; it has been seen fairly to meet and co-ordinate the very numerous and hitherto, for the most part quite unrelated problems which were enumerated at the outset, and even to be applicable to numerous minor and unexpected problems which these suggested. And thus, were it even viewed from the standpoint of mathematical probability alone, it has received the most overwhelming verification.

(*Explanation of the Plate at page* 292.)

II. An Hypothesis of Cell Structure.

1. *Statement of the Problem.*—Great attention has, especially of recent years, been paid to the problem of cell structure, and a vast body of observations have been accumulated. Of these many are generalised; many, however, still remain unco-ordinated, and an hypothesis which attempts at once to unify these, to throw light upon the structural and functional aspects of contractile protoplasm, and to unite all these with that theory of the cell-cycle above propounded, is therefore not untimely, and may, even if not completely exhaustive or satisfactory, be at least suggestive of a better explanation. Let us survey a few of the main peculiarities of protoplasmic structure which any such hypothesis must aim at unifying.

The lowest amœboid organisms are simply granular masses of protoplasm, but higher forms exhibit a differentiation of a hyaline zone of "ectoplasm" around a more fluid and granular "endoplasm." The immense variability of form, size, and general appearance present among the rhizopods has never been sufficiently allowed for; so that there is ample reason for doubting whether great numbers of described species have any real distinctness. Yet the elongated and reticulated, granular and circulating pseudopodia of the Foraminifera, and the radiating, clear, and far less contractile pseudopodia of the Heliozoa and Radiolaria present a most vivid contrast, which we have as yet no means of explaining. The remarkable changes presented by ova both before and during fertilisation,* and the doubtless fundamentally similar phenomena exhibited during cell division, require to be accounted for; while the long dispute as to whether the "granules" of protoplasm are really granules at all, or are the optical expression of the intersections of a stroma or network of denser protoplasm, cannot be omitted. Such a hypothesis must also aim at throwing light upon the mystery of muscular structure, and must also deal even with such apparently peculiar and exceptional phenomena as that "aggregation of the protoplasm," first described by Mr Darwin as occurring in certain cells of insectivorous plants † (which, when in active digestion, or when subjected to chemical, electrical, or even mechanical stimuli, exhibit an aggregation, or rather segregation of the protoplasm into two portions—the outer more or less hyaline, but containing irregular and constantly-changing streaks and granules of a more refracting and fluid substance, in which the colouring matter, when present, became accumulated).

2. *Statement of the Hypothesis.*—Darwin soon extended these observations to the protoplasm of root hairs, and went on to indicate its wide prevalence throughout the vegetable kingdom. His researches were verified and extended by Francis Darwin,‡ who showed that these granules did not consist of sap, as some vegetable histologists had suggested, but were essentially protoplasmic in their nature. It is the object of the present paper to apply these facts to

* Balfour, *Embryology*, vol. i.

† Darwin, *Insectivorous Plants*, London, 1875.

‡ *Quart. Jour. Micros. Science*, xvi.

the explanation of such problems of cell structure and contractility as those briefly enumerated above.

On this view, the granules of such a low vegetable organism as *Torula* (disregarding, of course, sap vacuoles and fat globules) are aggregation products, an assumption by no means excessive, especially when we bear in mind the activity of the chemical changes which are going on during its life and growth. But if this step be taken, we cannot resist regarding the Amœba in the same way; its granules too are aggregation products, and the clear ectoplasm, when present, may be viewed as protoplasm in which aggregation is not occurring. The variations of amœboid organisms in more or less granular character (a fact familiar to every observer) is thus brought into obvious relation with the state of nutrition, or with the quality and quantity of external stimuli; and its observed increase when stimulated, and its diminution during the resting state, are thus naturally accounted for. In the same way, in the granular pseudopodia of the Foraminifera, aggregation is in progress, in the hyaline processes of the Heliozoon not so. The granules of cells in higher animals may be, at least to a very large extent, similarly explained; while the disputes as to the presence or absence of a stroma become clearer when we bear in mind the fact that Darwin's aggregation-masses are at least as often greatly elongated or spherical, and that they may run in any direction, and unite or separate to any extent. The remarkable differentiations of protoplasm visible during cell-division, as exhibited by ova (of course excluding yolk granules, &c.), may not improbably admit of the same explanation.

3. *Contractile Structures—Muscle.*—The excessively difficult problem of muscular structure has not as yet received any widely-accepted solution, and even respecting matters of observation the widest discrepancies exist. In many invertebrates we cannot even be certain whether the muscles are striped or non-striped, so contradictory are the observations, while in a recent important paper by Professor Haycraft,* the homogeneity even of striated muscle is maintained. Brilliant light has, however, been lately thrown upon the arena of controversy by Professor Rutherford's recent elaborate demonstration † that the discrepancies in observation are largely

* *Proc. Roy. Soc. Lond.*, 1881.
† *Proc. Roy. Soc. Edin.*, 1883.

if not indeed altogether, to be explained by the fact that the different observers have studied their specimens in different stages of contraction. When fully extended, and then alone, the full complexity of the structure of striped muscle can be realised; with slight contraction Flögel's granules disappear, then Dobie's globules; finally, in completed contraction, the heads of adjacent sarcous elements come together, and the fibril is momentarily homogeneous, the former complexity reappearing on extension. So far Professor Rutherford's explanation—how does this come into relation with the present hypothesis? The doubly refracting portions of the muscle-fibrils may, on this view, be regarded as aggregation granules; for these must inevitably exhibit considerable regularity of form and arrangement, when we bear in mind that, if we admit the existence of muscle-fibrils at all, we imply that these possess a limiting surface,—of course tubular in form and ultra-capillary in fineness,—and still more so, if we assume with many histologists the existence of fixed points afforded by Krause's membrane.* In short, it is attempted to compare the aggregation-granules of a sundew, not only with those of an amœba, but even with those most complex and most peculiar differentiations of protoplasm observable in muscular tissue.

4. *Confirmatory Evidence.*—The present hypothesis is thoroughly in accordance with recent researches as to the nature and composition of protoplasm. Thus Brass† distinguishes cells into two layers,—the outer sensory, the inner nutritive, and describes phenomena which seem at least closely akin to aggregation.

Our knowledge of the development of muscle also supports the hypothesis. Thus, for instance, Wagener‡ shows that muscular fibres at first differentiate from the protoplasm of multinucleate cells, as perfectly smooth fibrils ("vollig glatte Fāden"), with interfibrillar substance. Later there arises, as a secondary differentiation, the refracting and non-refracting elements ("Isotropen and Anisotropen"), which can extend and diminish, also fuse together and again separate. In young heart-muscles these come and go under the observer's eye.

* *Cf.* Author's Prel. Note in *Zool. Anzeiger*, No. 146, 1883.

† Brass, *Zool. Anzeiger*, 120, 1882.

‡ G. Wagener, "Ueb. d. Entstehung. d. Querstreifen auf d. Muskeln," *Archiv f. Anat. u. Physiol.*, *Anat. Abtheil*, p. 543.

5. *Further Study of Aggregation—Cellular Therapeutics.*—High as is the importance of observations upon preserved tissues, the present hypothesis clearly points towards the importance of continuous observation of living cells when treated with various reagents—a line of research which Professor Frommann* is at present almost alone developing, and with such remarkable results. We must observe the effects, not of ammonic carbonate only, but of the whole pharmacopœia, and not upon the tentacles of Drosera merely, but upon vegetable and animal cells and tissues from the lowest to the highest; noting the changes which take place in all the structures and functions of the cell, and this, under all variations of temperature, light, electric state, and for various periods of time.

Of the practicability and interest of such an investigation only a single instance need be taken. When one treats an *Actinosphœrium* with dilute ammonic carbonate, the most striking change results; its pseudopodia disappear, its complex protoplasmic structure vanishes; it loses its regular spherical shape, and collapses into an irregular granular amœboid mass with blunt pseudopodia—(the very likeness of the ancestral amœba),—and then soon breaks up.

And similarly there is little doubt that such a reagent would produce marked effect upon the epidermic cells of growing tadpoles,—a convenient means of research. Thus we set out from these researches of Mr Darwin upon a general investigation into what changes chemical substances produce upon cells,—an investigation which touches the general question of pharmacy and therapeutics in the most direct way, and which we may in fact speak of as cellular therapeutics. The interest of the admission of a drug does not end when it has been conveyed into the stomach, but really begins there. We must know what happens to the component cells of the organism,—we must, in short, observe the therapeutic effects of reagents upon the cells of vertebrates,—an investigation which points far. Such observations would not require constant but only frequent attention for long periods, and are thus perhaps especially suitable for the skilled pharmacist.†

* Frommann, "Untersuch. ueb. Struktur, Lebenserscheinungen u. Reactionen thier. u. pflanz. Zellen," *Jena Zeitschr.*, xvii. and sep. pub., Jena, 1884.

† *Cf.* Author's paper in *Jour. Pharmaceutical Soc. Lond.*, No. 714, 1884.

6. *Further Chemical Considerations.*—It is an observed fact that when amœboid cells unite into a plasmodium, there takes place the most remarkable intensification of the activities of the mass. The compound amœba seem possessed of all and more than all the activities of its component amœba—pseudopodia of the most extraordinary length and size are thrown out, and motion is far more rapid; in short, it would seem that not only are the activities of the component amœba summed but multiplied. The coalescing amœbæ may be regarded as serving as food to one another—their waste products and their surplus water are squeezed out and got rid of, and thus we can readily understand the summation of their activities. But how is this apparent multiplication of activity to be explained?

We have seen how carbonate of ammonia, an oxidised body isomeric with urea, is exceedingly stimulating to protoplasm; and Mr Darwin's researches have also shown that other alkaloids and waste products are excessively stimulating, and set up the most extraordinary aggregation; and that a poison, for instance, may act by excessively exaggerating this normal process. Here then is a use, not merely for the protoplasm, but actually for the waste products—the waste product of one cell acting as a stimulant when it meets the protoplasm of another. And from this consideration again new series of speculative applications radiate off in all directions. One may suggest that the use of the alkaloids in the coffee or strychnine or Calabar bean is not merely to protect the young embryo from being eaten by animals, but as a stimulant to germina tion. Or we may introduce the same conception into our speculations as to the uses of manures, in which the most valued constituents are precisely those salts which, like carbonate of ammonia, produce great aggregation.

Again, passing from the plasmodial union of cells to the probably derived union of ovum and spermatozoon, we cannot avoid imagining the latter bringing not merely a trifling contribution of additional protoplasm, but a store of substances especially stimulating to the vast mass of the ovum. And the identification above suggested of aggregation with the protoplasmic changes visible in the ovum after fertilisation, is thus seen to be by no means so improbable as might at first appear.

7. *Need of an Explanation of the Phenomena of Aggregation.*—

How is it that if we treat living protoplasm with certain reagents it breaks up into two substances? How are we to explain this observed fact? Is there any case known to chemists or physicists where a chemical reagent separates a substance, at first apparently homogeneous, into two distinct substances which afterwards reunite; or where an electrical or mechanical stimulus temporarily separates a complex mixture into its components? I am not aware of any parallel case; but the absence of an explanation underlying the phenomenon of aggregation itself is after all entirely outside, and subsequent to both the main thesis and the speculative corollaries of the present paper.

III. An Hypothesis of Contractility.

If we imagine a single drop of more or less fluid substance suspended in a surrounding medium with which it does not mix, its surface-tensions tend to keep it in a spherical form. This can of course be observed in a drop of oil or water, most conveniently in the well-known experiment in which oil is suspended in a mixture of alcohol and water of the same specific gravity. If now we interfere and elongate this drop, its surface tensions at once enable it to resume the spherical form, even against the resistance of the surrounding medium. It is inevitable to transfer this simple physical conception to explain the function of muscle. If the elongated components of the muscular fibre be more or less fluid (as we almost certainly know them to be, whether aggregation granules or not), they must needs also possess surface tensions; they must, therefore, also tend to shorten and broaden, and draw themselves into a sphere. And if all these multitudinous elements of the muscle are shortening and broadening, we have of course an explanation of that general shortening and broadening which we term the contraction of a muscle.

Moreover, just as the "contracting" drop of oil overcomes a resistance, so the "contracting" muscle overcomes a resistance equal to the sum of the minute resistances which the millions or thousands of millions of simultaneously contracting elements can overcome. Finally, an expenditure of energy must needs take place, and of this the "negative variation" of contracting muscle (perhaps of the contracting oil-drop also?) may afford the indication.

Be the latter suggestion valid or not, it is important to observe (1) that we have here (and for the first time so far as the writer is aware) an hypothesis which explains (*a*) the shortening and broadening of a contracting muscle, (*b*) its overcoming a mass resistance, in other words, that we have an explanation of the mode in which almost molecular movements are converted into movements of masses, a solution long sought by physiologists; and (2), that this hypothesis depends simply upon the more or less fluid nature of the essential muscular components, and is entirely independent of the acceptance or rejection of the hypothesis of the preceding paper, which suggests the identification of these muscular components with aggregation granules.

Explanation of Plate IV.

In columns allotted to the four stages of the cell-cycle (encysted, ciliated, amœboid, and plasmodial) are arranged the corresponding phases of the form-history of a few typical Protozoa and Protophytes, as also a series of diagrams illustrating the normal and pathological form-history of the cells of higher plants and animals. All are thus seen to be referable to the Protomyxan or Myxomycete type.

Among the Protozoa proper (figs. 3–8) the cell-cycle is almost complete; the encysted and amœboid stages are invariably represented. The plasmodial phase is of frequent occurrence: in Infusorians, Gregarines, and Heliozoa that of multiple conjugation representing it, and demonstrating its essential continuity with conjugation, *e.g.*, diatoms and algæ (figs. 10–13), and even with fertilisation in plants and animals (figs. 14 and 16).

Fig. 18 shows the cell-cycle in a developing gastrula, *e.g.*, sponge. In fig. 19 the various tissues are classified in relation to the cell-cycle; the connective tissues to the encysted, the muscular to the amœboid type, &c., even the plasmodial phase being represented during the histolysis of Polyzoa. Fig. 19 represents the development of an invertebrate amœboid corpuscle, and fig. 20 its formation of a plasmodium when drawn, while figs. 20–25 continue the application of the same theory to the explanation of pathological change.

Monday, 17th December 1883.

ROBERT GRAY, Esq., Vice-President, in the Chair.

The following Communications were read :—

1. On the Change in the Peltier Effect due to Variation of Temperature. By Albert Campbell. Communicated by Professor Tait.

The object of this short paper is to give the results of some further experiments made with a view to determine the variation in the Peltier Effect due to change of temperature. These experiments are the continuation of a set of similar experiments described in a paper read to the Society in summer 1882.

The arrangement used was almost exactly the same as that employed in the former experiments—the measurements being made by means of an iron-German-silver thermopile bent into the shape of an arch, with the ends about $\frac{1}{4}$ inch apart, and placed so as to almost touch the junctions of the metals whose Peltier Effect was to be measured.

The neutral-points of the various pairs of metals were also measured in the usual way by heating up a junction in oil, plotting the temperature-deflection curve, and from it deducing the neutral-point. According to theory, the ratio of the Peltier Effect at temperature t_1 to that at t_2, is determined *solely* by the values of t_1, t_2, and the neutral-point of the metals used; therefore it was not necessary to draw the thermo-electric lines of the metals.

As I have no satisfactory measurement of the neutral-point of Pb–Arg, in this case the calculated ratio in column V. is from Professor Tait's diagram.

In the subjoined table, column I. gives the name of the pair of metals; II. and III. the lower and upper temperatures at which the Peltier Effect was observed; IV. the ratio of the Peltier Effects at these two temperatures *from the direct measurement;* V. the ratio calculated from the observed neutral-point given in VI.

I.	II.	III.	IV.	V.	VI.
Fe–Zn . .	23°·8 C.	99° C.	1·43	1·404	198° C.
Fe–Zn . .	28°·25	94°	1·373	1·3397	198°
Fe–Zn . .	24°·5	94°	1·429	1·353	198°
Pb–Zn . .	17°	96°·8	·416	·4275	– 79°
Pb–Zn . .	18°·25	96°·5	·488	·434	– 79°
Zn–Arg . .	18°	98°·5	·730	·638	– 330°
Zn–Arg . .	18°·5	86°·5	·718	·678	– 330°
Pb–Arg . .	18°·6	95°·5	·682	(·636)	...

[*Note.*—Mr Campbell sent me portions of his iron and German-silver wires to test. The electromotive force of a circuit of these wires was found to be almost exactly proportional to the difference of temperatures of the junctions between 10° C. and 100° C.—P.G.T.]

2. On the Problem of the Lathe-Band, and on Problems therewith connected. By Edward Sang.

That of the lathe-band is one of those simple-looking problems in elementary mechanics which present serious difficulties to the investigator. The problem is this—"So to arrange the several diameters on the fly-wheel and pulley-cone of the turning-lathe, as that the same band may suit for all." The solution consists of two steps converse to each other, the one being "to compute the length of the band from given diameters," the other "to compute new diameters which may suit the length so found."

If A represent the lathe centre, B the centre of the fly-wheel, and if a circle be described round B, having its diameter KBH equal to the difference between the diameters of the wheel and pulley, the two tangents GA, Ag, together with the arc gHG, give the excess of the length of the band over the circumference of the pulley, while the same two tangents exceed the arc GKg by as much as the band

is longer than the circumference of the wheel. Now, if we write i for the angle GAB, and regard AB as the unit of linear measure, we easily find

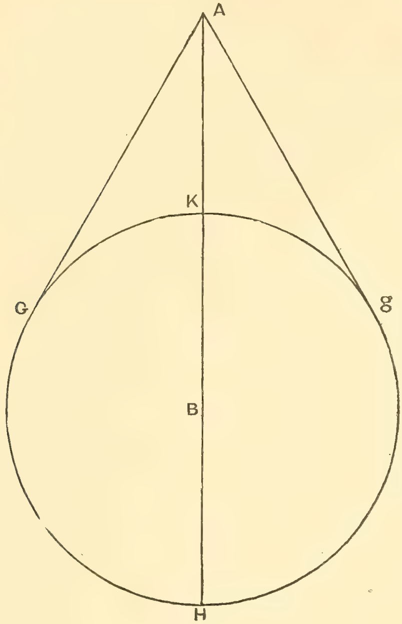


Fig. 1.

$$AG + GH = \cos i + (\tfrac{1}{2}\pi + i) \sin i = l\,;$$

$$AG - GK = \cos i - (\tfrac{1}{2}\pi - i) \sin i = l'.$$

Since i can be found from the difference of diameters, or that difference from i, the two branches of our problem come eventually to be "to find l and l' from i," and "to find i when l or l' is given." The first question is solved by help of the canon of sines; the second presents greater difficulty, we can get the value of i from that of l only by a series of trials. Yet, in truth, there is no essential difference between the two processes, both consist of trials; but the existence of the canon of sines, renders the trials in the former case so easy, that we come to regard the operation as direct. If we had a table of the values of l corresponding to all values of i from zero to the right angle, we would be able to resolve both problems with like facility.

In applying such a table to the business in hand, we should have to compute the circumference from the diameter, and afterwards the diameter from the circumference. This double arithmetical operation may be avoided by the simple contrivance of counting all in diameters; for the *length* of the band, we substitute the *diameter* of the circle which it would gird. Writing them

W = diameter of wheel,
P = diameter of pulley,
B = diameter for band, we have

$$W - P = 2 \sin i,$$

$$B - P = \frac{\cos i}{\frac{1}{2}\pi} + \left(1 + \frac{i}{\frac{1}{2}\pi}\right) \sin i,$$

$$B - W = \frac{\cos i}{\frac{1}{2}\pi} - \left(1 - \frac{i}{\frac{1}{2}\pi}\right) \sin i.$$

From a table constructed according to these formulæ, the dimensions of the lathe may be got by little more than inspection.

The actual table and the mode of using it, exhaust the mechanician's interest in the subject, but, to the speculative mathematician, some connected points may appear to be deserving of notice.

Our ordinary tables, arranged according to the ancient graduation, are exceedingly inconvenient, because the ratio $\frac{i}{\frac{1}{2}\pi}$ expressed in degrees and minutes would involve, in each case, a troublesome division. The decimal subdivision of the gradient was therefore preferred, and the computations made for each thousandth part, that is for intervals of 10′ centesimal. A manuscript canon of sines to 15 places (using however only 10 of these) rendered easy the computation of the terms

$$\left(1 + \frac{i}{\frac{1}{2}\pi}\right) \sin i \text{ and } \left(1 - \frac{i}{\frac{1}{2}\pi}\right) \sin i.$$

The canon of "sines measured in degrees" had been prepared, in order to compile the table of circular segments, used for the computation of the anomalies of the planets; the term $\frac{\cos i}{\frac{1}{2}\pi}$ was thus ready to hand. In this way the construction of the table for lathe-bands was greatly facilitated.

In all such calculations, the residual last-place errors may happen

to balance each other, or may happen to concur in one direction, hence there is a possibility of error in the last place, proportional to the complexity of the work. This error may, in the present instance, amount to 2 or even 3 units in the last place. Hence it follows that, in shortening from *ten* places to the *six* places in the final table, an uncertainty in the sixth place must occur when the rejected figures are within the limits 4997 and 5003, as happens thrice in the course of the work. Hence the necessity for founding our working tables on more extensive ones.

All possible cases of the mechanical problem are comprised between the limits $i=0$ and $i=\frac{1}{2}\pi$; while i passes from the one to the other of these limits, the line AG makes the quarter of a turn, and we naturally inquire, What happens when the motion is farther continued? or how was it on the other side of the zero?

On changing the sign of i, the expressions for B – P and B – W change places; the wheel takes the place of the pulley. This is clearly seen in the second figure; the change from DC with its inclination inwards, to D′C′ inclined outwards, is accompanied by a reversion in the sizes of the circles. Hence it will suffice for us to examine the phases for values of i beyond the right angle.

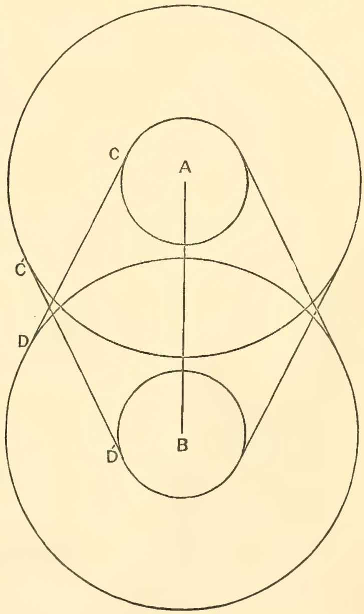


Fig. 2.

In order to this, let the circle described with the radius AE, fig. 3, represent the pulley, which we shall suppose to remain unchanged while the inclination of the band varies. When that inclination is zero, as in the position D_0C_0, the wheel is of the same size as the pulley; but when the band is inclined, as in the position DC, the radius of the wheel has grown to be BD or BM, and the half length of the band is made up of the three parts FD, DC, CE. When i becomes a right angle, the points

D and C have come up E, and the band encompasses the whole circle whose radius is BE.

Imagine now that the point of contact C has passed beyond E into the position c; the tangent takes the position dc, so that the course of the band is from F along the arc FDMd and back along

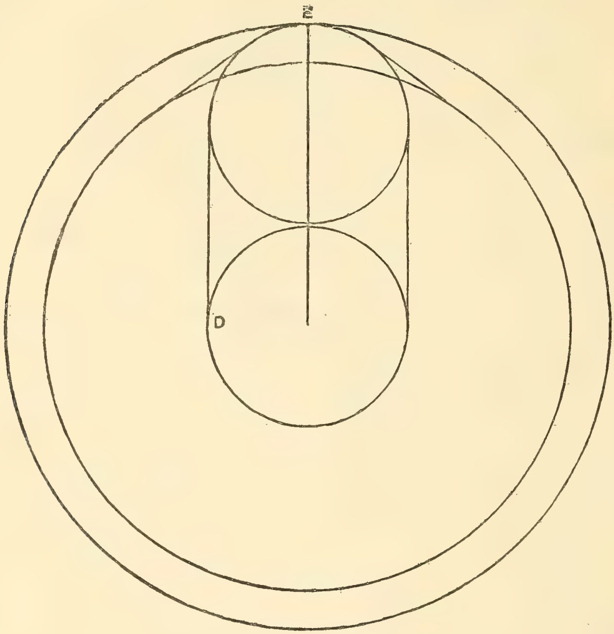


Fig. 3.

dcE to E; the half-length being still made up of the three parts Fd, dc, cE; but in counting the length dc and cE must be regarded as subtractive.

In this way the imaginary band is shorter than the circumference of the wheel, by as much as, in the symmetric position, the actual band had been longer.

Beyond the limits $i = \pm\frac{1}{2}\pi$, the mechanical arrangement fails to illustrate the properties of the above expressions, and therefore, regarding them as purely analytical formulæ, we may proceed to examine their characters.

Placing the arc i, representative of the inclination, along the line of abscissæ, and setting up the values of l and l' as ordinates, we

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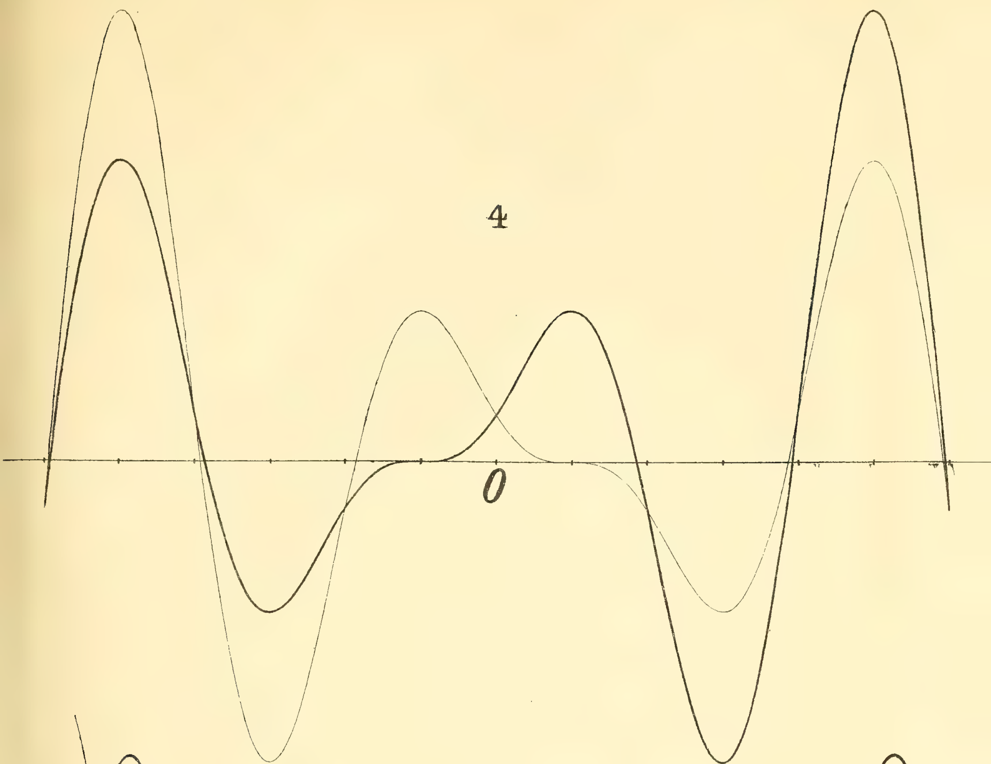

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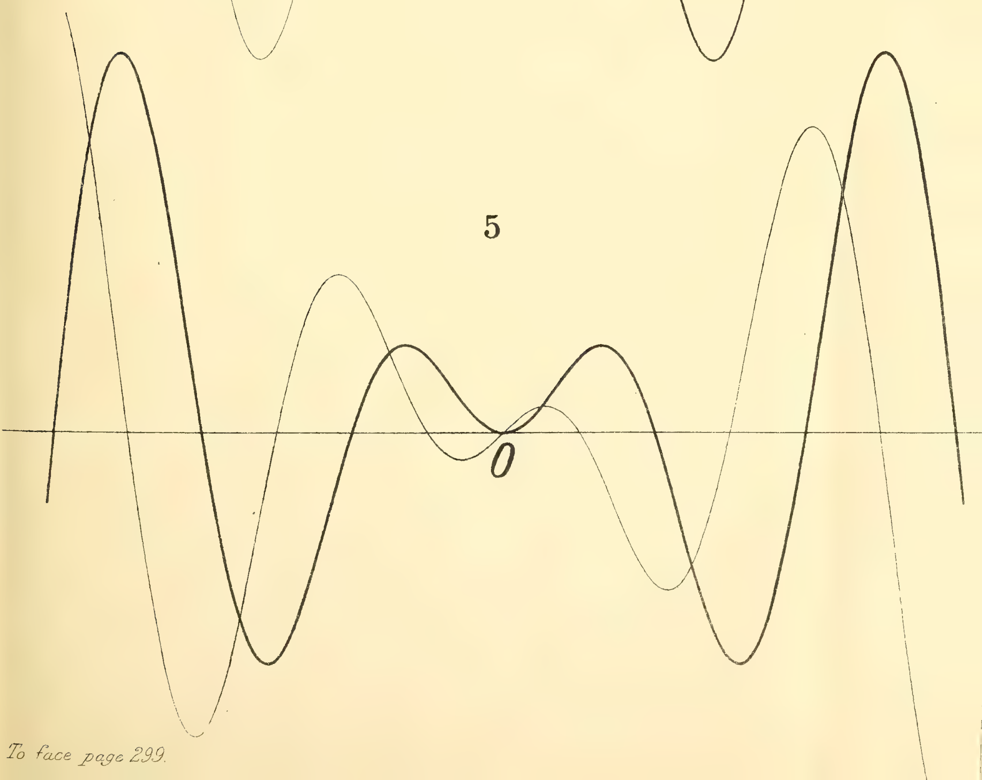


To face page 299.

obtain the curves shown in fig. 4; symmetrically placed in regard to the origin O; the one curve being converse to the other.

We may put these formulæ in a more convenient form by transposing the origin of abscissæ in the one case to $-\frac{1}{2}\pi$, in the other to $+\frac{1}{2}\pi$; for this purpose we write $x=\frac{1}{2}\pi+i$ or $-x=\frac{1}{2}\pi-i$, and in this way confine our attention to one of the curves, whose equation now becomes

$$l = x\cos x - \sin x.$$

In order to determine the singular points in the curve, we must take the first and second derivatives (differential coefficients) of this expression; these are

$$\frac{\delta l}{\delta x} \text{ or } {}_{1x}l = x.\sin x,$$

$$\frac{\delta^2 l}{\delta x^2} \text{ or } {}_{2x}l = +x.\cos x + \sin x;$$

and continuing the derivation,

$$\frac{\delta^3 l}{\delta x^3} \text{ or } {}_{3x}l = -x.\sin x + 2\cos x,$$

$$\frac{\delta^4 l}{\delta x^4} \text{ or } {}_{4x}l = -x\cos x - 3\sin x,$$

etc. etc.

The remarkable simplicity of this progression suggests the continuation in the opposite direction; taking the successive primitives (integrals), we get

$$\int\delta x.\, l \text{ or } {}_{-1x}l = -x.\sin x - 2\cos x,$$
$$\iint\delta x^2.l \text{ or } {}_{-2x}l = +x.\cos x - 3\sin x,$$
$$\iiint\delta x^3.l \text{ or } {}_{-3x}l = +x.\sin x + 4\cos x,$$

and so on;

and it is obvious that, in this endless progression of derived functions, the appropriate middle term is $x.\sin x$, which also has its conjugate $x.\cos x$. Denoting the one of these functions by $\mathrm{F}x$, the other by ϕx, we have the conjugate progressions:—

etc.	etc.
${}_{-4}\mathrm{F}x = +x.\sin x + 4\cos x$	${}_{-4}\phi x = +x.\cos x - 4\sin x$
${}_{-3}\mathrm{F}x = +x.\cos x - 3\sin x$	${}_{-3}\phi x = -x.\sin x - 3\cos x$
${}_{-2}\mathrm{F}x = -x.\sin x - 2\cos x$	${}_{-2}\phi x = -x.\cos x + 2\sin x$
${}_{-1}\mathrm{F}x = -x.\cos x + \sin x$	${}_{-1}\phi x = +x.\sin x + \cos x$
$\mathrm{F}x = +x.\sin x$	$\phi x = +x.\cos x$
${}_{1}\mathrm{F}x = +x.\cos x + \sin x$	${}_{1}\phi x = -x.\sin x + \cos x$
${}_{2}\mathrm{F}x = -x.\sin x + 2\cos x$	${}_{2}\phi x = -x.\cos x - 2\sin x$
${}_{3}\mathrm{F}x = -x.\cos x - 3\sin x$	${}_{3}\phi x = +x.\sin x - 3\cos x$
$\mathrm{F}x = +x.\sin x - 4\cos x$	${}_{4}\phi x = +x.\cos x + 4\sin x$
etc.	etc.

each term being the derivative of that above it.

On equating any one of these functions to zero, we get (1st) the intersection of its curve with the line of abscissæ, (2nd) the culminations of the curve belonging to the function immediately above, and (3rd) the points of reflexure of the curve of two steps up; hence we are mostly concerned with the solution of the general equation

$$ {}_{n}\mathrm{F}x \text{ or } {}_{n}\phi x = 0\,. $$

The equation $\mathrm{F}x = x.\sin x = 0$ is satisfied in two ways, by making $x=0$ or by making $\sin x = 0$. Now $\sin x$ becomes zero for every value of $x = n\pi$, n being any integer positive or negative number, and hence the curve, shown in fig. 5, crosses the line of abscissæ at equal intervals of π, counting from the zero point; and since $x=0$ coincides with one of the values $\sin x = 0$, the curve touches the axis at the origin.

The conjugate equation $\phi x = x.\cos x$, is also satisfied by putting $x=0$ or by $\cos x = 0$, the latter condition giving for x any value of the form $(n+\frac{1}{2})\pi$; hence, besides the crossing at the origin, this curve crosses the axis of abscissæ at points distant by the interval π, reckoned from $\frac{1}{2}\pi$ on either side of the zero.

The solution of the adfected equations is somewhat more complex. Beginning with the case ${}_{-1}\mathrm{F}x = -x\cos x + \sin x$, which is that of the actual lathe-band, we observe that the function becomes zero when the condition

$$ x = \tan x $$

is satisfied. We have thus the problem "to find an arc equal to its own tangent."

Having applied, at the end of the radius OA, a tangent to the circle, let us suppose two points thence to set out with equal velocities, the one q to travel along the tangent, the other p to move along the circumference of the circle, carrying with it an indefinitely

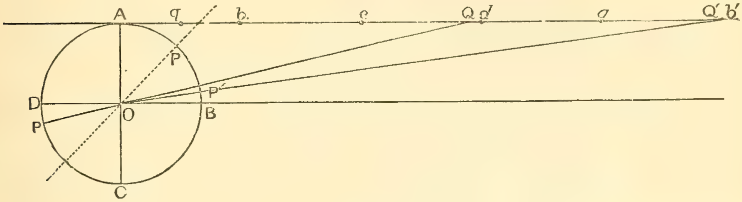


Fig. 6.

extended radius Op. At first this secant will precede the point q, and by the time q has reached the distance Ab, equal to the quadrant AB, the intersection has moved off to an infinite distance along to tangent. After this the point of intersection reappears on the other side and comes up to A just when q reaches the distance Ac equal to the half-circumference ABC. The intersection now chases the travelling point q and comes up to it at Q, somewhat before p has reached the third quadrant. The first root of our equation, that is AQ or ABCP, is below the value $x = \frac{3}{2}\pi$. In the same way we readily perceive that the next root is when p has made more than an entire revolution by nearly a quadrant, that is when it has come to P′ a little before B; the root, then, is rather less than $\frac{5}{2}\pi$.

The numerical values may be found by a very rapid approximation. Assuming $x = \frac{3}{2}\pi = \mathrm{A}a$, we compute the arc of which this is the tangent; we regard the length of this arc as a new tangent, compute the length of the arc thereto belonging, and so continue until there be no change within the limits of the precision at which we aim. Three or four operations exhaust the precision of seven-place tables. The successive approximations are thus represented by the symbols

$$\tan^{-1}(\tfrac{3}{2}\pi),$$
$$\tan^{-2}(\tfrac{3}{2}\pi),$$

and so on, so that we have $x = \tan^{-\infty}(\frac{3}{2}\pi)$; where ∞ stands for an indefinitely large integer number.

The roots of this equation are actually

$$\begin{array}{rcl} & c & r \\ 257^\circ\cdot27 = & 286\cdot06 = & 4\cdot4934 \\ 442\cdot37 = & 491\cdot80 = & 7\cdot7252 \\ 624\cdot46 = & 694\cdot17 = & 10\cdot9041 \\ 805\cdot56 = & 895\cdot48 = & 14\cdot0662 \end{array}$$

For the crossings of the curve belonging to the function ${}_1Fx$, we get the condition

$$x = -\tan x\,,$$

and, in this case, the points p and q must move away from A in opposite directions, and the first coincidence will take place when p is somewhat beyond the extremity of the quadrant AB; the phases are so closely analogous to those of the preceding case that it is unnecessary to detail them.

The functions ${}_1\phi x$ and ${}_{-1}\phi x$ give the conditions

$$x = \cot x \text{ and } x = -\cot x\,.$$

In these cases, when q begins its motion from A along the tangent, the travelling point p must leave B, in the one case travel-

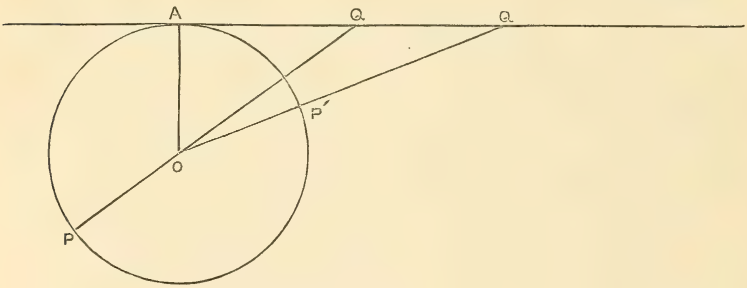
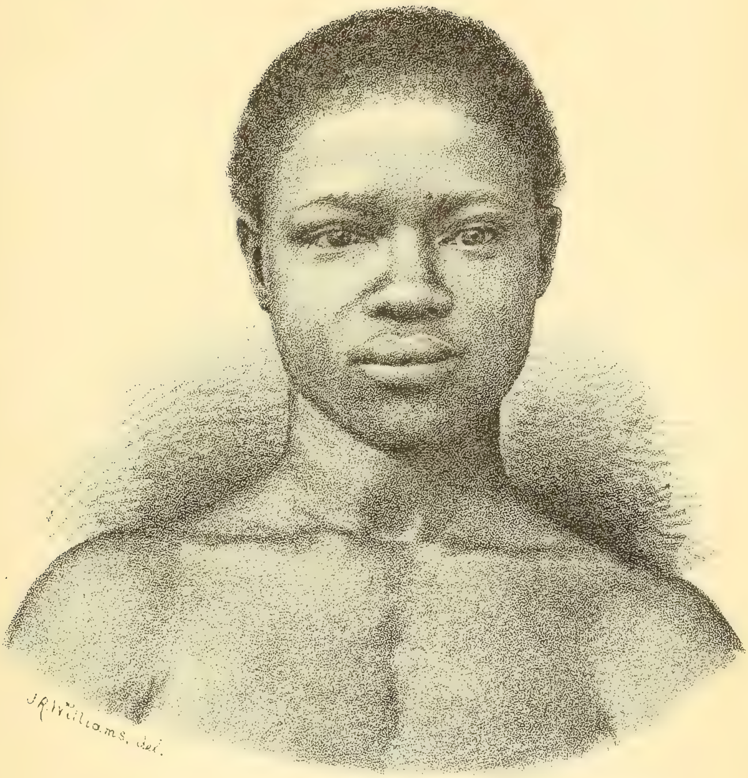


Fig. 7.

ling backwards towards A, in the other case forwards towards C. Thus the same artifice serves for the detection of the roots in all the four equations.

As an example of the other cases, we may take the function ${}_{-3}Fx = x\cos x - 3\sin x$; this, when equated to zero, becomes

$$x = 3\tan x\,.$$



A MADI OR MORN BOY, AGE ABOUT 17.

We shall therefore suppose that the travelling points p and q leave A simultaneously in the same direction, but that p moves thrice as fast as q; here we see that the radius Op must make more than half a turn before its intersection with the tangent can overtake q. Proceeding by the same method of approximation, we readily find the arc AP to be 233° 40′, its tangent AQ being 1.3594 in terms of the radius. Each succeeding coincidence must occur after an interval of rather more than half a turn, so that the approximations are rapid. The second coincidence is when x = AP′PAP′ reaches 428° 07′, the tangent AQ′ being 2.4907.

The same method is applicable to the other cases of the general problem.

Thus the consideration of this elementary problem in mechanical construction leads us to examine the properties of a whole class of functions, which, again, may serve to suggest further extensions and inquiries.

3. Notes on the Madi or Moru Tribe of Central Africa. By Robert W. Felkin, F.R.S.E., F.R.G.S., Fellow of the Anthropological Societies of London and Berlin, &c. (Plate V.)

The following notes have been compiled from my own observation, when in Central Africa in 1880, from inquiries I made on the spot, and from the information I have obtained from a native who has been my faithful servant during the past few years.

They treat of a people inhabiting a large tract of country situated 5° N. lat., 30° 20′ E. long. of Greenwich, of which the chief town is said to be Bengué.

The Arab customs, which are being introduced among the races in Central Africa, are rapidly breaking down the boundaries which exist between the tribes, and superseding their primitive habits and customs, which in a few years will be things of the past. For this reason I have been induced to bring together all the information it has been my good fortune to collect, and whilst regretting that the record is not so complete as one could have wished, I yet hope that it may prove of some value, or at all events of interest, to those engaged in the study of anthropology.

The tribe called Madi by the Arabs give themselves the name of Moru, and must not be confounded with the Madis on the east of the Nile, or with another so-called Madi tribe on the west.

I am not able to give the exact population of the district, but I have ascertained that it has diminished considerably during the last ten years, owing to the fact that many of the people have been taken away as slaves, while numbers of the young men have been drafted into the Egyptian army, where they have obtained a reputation for courage, fidelity, and veracity.

I will commence by giving a description of the way in which the Madi builds his hut, so that you may first see him in his home, and then follow him as he goes to his daily work, or enters into the various pursuits of a far from monotonous life.

Habitations.—The process of constructing a hut is as follows:—A circle is marked on the ground by means of a string attached to a stick in the centre, and in this circle poles are fixed into the earth. These poles are made from thick straight peeled branches of a tree called "pi," and they are encircled by rows of supple saplings, which are tied to them at intervals of about 1½ feet. Grass is then taken, cut the same length as the poles, about 6 feet, and placed upright in bundles round the framework, after which saplings are again tied round to keep the grass in position. The roof is made on the same plan, a strong circular foundation of wood being first put together, into which wooden rafters are fixed, and being brought together in the centre, are secured at their upper ends. Circles of saplings are fixed on to the rafters, and then grass is laid on, and fastened as in the case of the wall. The top of the roof is formed of a large bundle of grass cut even and bound firmly together at the lower end. A stake about 4 feet high is thrust through it, and then fastened on to the top of the roof. The loose ends of grass are then bent downwards, and secured to the roof, and the free end of the stake is ornamented by an ostrich egg and feather.

There are no windows in these huts, and only one entrance, about 3½ feet high and 2½ feet wide; a door of wicker work is made to slide backwards and forwards inside across this entrance, and is kept in place by two poles fixed firmly in the ground, and tied at the top to the roof.

Trenches are dug round the huts before the rains set in at a sufficient distance for the water dripping off the roof to fall into them. A small channel from the trench carries off this water to a convenient distance.

Furniture.—These dwellings do not contain many articles of furniture. The principal one is the bed, which is made from the stem of a plant called yougo, resembling the sugar cane. Narrow pieces of the stem are cut about 6 feet long, laid side by side, fastened together by strips of cow hide, and then fixed on to three wooden cross bars. This is raised from the ground about 3 feet upon six thick round wooden legs, to which the cross bars are tied, the whole is then covered with a cow hide.

A large earthenware jar is an indispensable piece of furniture. It is about 4 feet deep and 5 feet wide, with a narrow neck, and is placed on a wooden stand, generally formed of the forked branch of a tree. It contains a good supply of semsem seed (Egnoir), which is used for making porridge, and from which oil is obtained. Another jar of the same shape, but smaller, contains water, and is placed near the entrance.

The bare ground, which is well trodden and beaten to make it firm, forms the floor, and a wood fire is generally burning in the centre of it. Jars of varying shapes and sizes are placed round the hut on the floor, or hung from the walls in string nets. They contain different kinds of dhurra, also honey, butter, dried sugar cane, salt, &c. Baskets made of dhurra stalks are also hung round the hut, more for ornament than use it would seem. Bundles of arrows, spears, bows, and knives serve the same purpose when not in use.

Besides the principal hut, each family usually has a hut for strangers; and as soon as children arrive at the age of four or five years, the father builds a separate hut for the girls and one for the boys, or several neighbours club together in these huts. These additional buildings contain only beds, a water jar, and a few basket work ornaments.

Granaries.—Another erection is constructed as a storehouse for dhurra. The circular wall is made like that of the other huts, of poles and grass, but it has a flat wooden roof upon which is fixed an upper chamber of basket work (literally a huge basket), in which the dhurra is kept. Over it is placed a roof similar to the one de-

scribed above. This roof is kept in place by three poles which pass through its outer rim, and are fixed into the ground below, apart from the walls.

The lower part of this building is used as a kitchen, and contains a number of large stones for crushing corn, and jars for holding it. Meat is also hung from the ceiling. The dhurra can only be taken out of the granary from above. The roof is pushed up with a long pole, which when rested on the ground keeps it raised; a woman then ascends from outside by means of one of the three supporting poles, which is a kind of ladder, for it is made of a tree stem, the broken stumps of branches forming the steps.

Gardens.—Flowers are cultivated close round the dwelling huts, but the garden, which seems to be an indispensable belonging, lies behind the hut, covers generally a large extent of ground, and is devoted to the cultivation of fruits and vegetables. The beds are circular and raised about 3 feet, falling abruptly to the ground all round. Melons, gourds, and vegetable marrows are grown on them, and creep gracefully down the sides and along the unoccupied ground beneath. Some beds are 3 feet wide, and of great length, and are planted with sogo (yams?), which twine up a double row of sticks about 12 feet in height.

A poisonous bulb, in appearance like our onion, is planted round the dwelling, and its leaves are put about the huts to keep away serpents and mosquitoes. Arrows are also poisoned with it.

Cattle.—Cattle forms the chief wealth of the tribe. A rich man may have as many as 200 head, a very poor one only three or four. The average number possessed by one man is from thirty to forty. A large enclosure (or kraal) is erected for them at a short distance from the village, and cows belonging to different families herd together in one kraal. This is circular, with strong wooden walls and no roof. Inside there are two smaller enclosures—one for the calves, and one for the man in charge, the latter having a roof of wood and grass. A fire is made between these two divisions. Should the rains be very heavy, a temporary roof is constructed for the calves; sometimes even, the people take them into their own huts. The care of the cattle is not the work of one man in particular, but the owners take it in turns to sleep with them at night, and take them to grass by day. Cattle are never let out to graze

till the dew is off the grass; eating wet grass is said to cause a plague. They are milked by men, and women make butter from the milk in gourds. The cows are called by names, either according to their marking, or, if favourite ones, after some near relation of the owner. They are not branded or marked in any way, but identified without. If a cow is troublesome, a bell is put round its neck.

In the holiday season the cows are taken by young men and boys to a distance, for change of air and food, and brought back after a few weeks. The people in whose district the cattle feed are permitted to use the milk, and in return provide the keepers with food and shelter.

There is a special kind of black cow (sometimes red), whose milk is kept solely for its master's use, or for its calf. A man usually possesses at least one such animal.

It is usual to kill cattle at the beginning of the rains, when they are needed for food by the people employed in sowing the crops.

Cows suffer from sore legs and serpent bites. In the first case, they are killed and eaten, but the flesh of those bitten by snakes is considered to be injurious.

Food.—The Madis consume a large amount of animal food, of which there is a great variety, especially in the hunting season.

The buffalo, tetel, wild boar, gazelle, and hippopotamus are all commonly eaten; while the elephant, rhinoceros, crocodile, eland, and fox are partaken of occasionally. Among domestic animals consumed are the cow, sheep, and goat, though cows are only eaten at harvest time and at funeral ceremonies. Wild ducks, pigeons, fowls, and guineafowls may be added to the list, and sometimes ostriches; but fowls are only eaten by young children and old people. Several varieties of fish are found in the rivers, and eaten.

Of the vegetables cultivated, marrows, cucumbers, sweet potatoes, yams, peas, beans, and greens are the principal; and the most common fruits are figs, nuts, melons, and the fruit of the date palm. Several varieties of dhurra are made into bread, as also occasionally a root called morako, but the bread is usually of the consistency of our porridge. A substitute for our butter is found in the semsem seed, which is roasted, ground, and eaten with

bread. When people cannot afford this, they have recourse to "bottled white ants." Butter is made, however, and when used, is melted and poured over the porridge. Both cows' and goats' milk is largely used. Marrow, which is extracted from bones with a stick, is much relished.

There do not appear to be any articles of food forbidden, but some people do not think it well to eat liver, fish, sheep's head, or goats. The earth thrown up by ants is sometimes eaten, but those who do it are considered mad.

Oil is made from semsem seed. The seed is ground, boiling water poured over it, and the oil squeezed out with the hand on a grinding stone, caught in a gourd, and poured into jars.

No spices are used, but redeb, a stone fruit, is made into a pulp, and mixed with porridge, when the latter is boiled. Salt is used, and is kept by some people for sale. Honey and deli stem are added to sweeten food.

The most expensive articles of food appear to be semsem, milk, cows, sheep, and goats.

Cooking.—The cooking is either done in the room under the granary, or outside the entrance to the dwelling hut, where three stones are always placed. Between these a fire is made, and the cooking vessels are placed upon the stones. The women are the sole cooks. They have a superstitious practice of putting white ashes on the pots before placing anything inside; some words are muttered at the same time, and this is supposed to make the food more satisfying when cooked. Small cooking operations are at times done in the hut.

Refuse is deposited in heaps about 100 yards from the hut, and cleared away periodically.

Meat will keep two days, but is considered at its best on the first day after killing. It is boiled and also roasted over the fire. Meat and fish are dried in the sun for keeping. Fresh fish is boiled; dried fish boiled or broiled. Fowls and all kinds of birds are boiled. No spit is used to roast meat; it is laid across two pieces of wood arranged over the fire. Meat is not fried. The use of hot stones in boiling is unknown. Porridge and bread are mixed in a pot over the fire, and bread is really only a very stiff porridge. Porridge mixed with redeb and semsem is made with water; that made of

dokn flour, with a little butter added, is boiled with milk. Vegetables are eaten alone, bread being used with meat.

The cooking vessels are earthenware jars. Mixing sticks are the only cooking utensils used besides knives. They are cleaned after use. No vegetable broths or stews are made. Farinaceous puddings are unknown. Meat very well cooked is preferred. Preserving of fruit with sugar and pickling of vegetables are unknown.

The only beverages are water, milk, and dhurra beer. This beer is made by the women in large quantities, and kept in jars in a hut set apart for the purpose. To this hut the people go to drink. It is common property, and not paid for. They do not take the beer home, or drink it at meals.

There are three meals in the day—before sunrise, at midday, and at sunset. No ceremonies are observed at the commencement of meals, nor are there any religious rites connected with them.

When fine, meals are taken outside the entrance to the hut near the cooking place. It is customary for members of different households to meet together for dinner, each family providing a bowl of food, round which they sit, and eat from one bowl after another, using their fingers as spoons and forks. They always wash their hands before and after meals, a jar of water being provided for the purpose, but the water is not poured over the hands. The men and boys sit in one group, the women and girls in another. The women do not wait on their husbands, the food when ready being fetched by the children. Any stranger who may chance to pass by is invited to share the meal. Water is always kept at the door of the hut to give to passers by. Wooden stools are used outside the dwelling, but it is not considered proper to use them at meals. The gathering does not disperse directly the meal is over, but digestion is aided by telling and hearing tales.

No cannibalism exists in the country, and the people express great abhorrence of the custom as practised by their neighbours the Nyam-Nyams.

Fire.—Wood is used for fire, and lighted with dried grass. The fire is produced by friction of wood, one piece of wood about the size and shape of a large pencil being rapidly rotated in a hole in a flat piece of hard wood. One man holds the hard wood steady, whilst two others take it in turn to rotate the stick

Smoking.—Tobacco is used to a great extent for smoking, but it is not chewed, nor used as snuff. The native name is tabba, which is, however, commonly used in other tribes also. I believe the tobacco smoked to be indigenous, for none is imported. It is very good, but exceedingly strong. It is cultivated, and the leaves, being sun-dried and broken up in small pieces, are then mixed with a small proportion of dried cows' dung and urine, and moulded into conical cakes, weighing about $\frac{1}{4}$ lb. to 1 lb. each. These cakes are dried in the sun, and stored away in baskets hung up in the huts.

Two kinds of pipes are used, both made of clay. One measures about six inches long, with a very thick stem and oval bowl; the stem is not put into the mouth, but the lips are pressed round the hole in it. The other pipe is itself small, but has a wooden stem about three feet long; this pipe is rarely carried about, but smoked in or near the huts. The pipe is ignited by burning charcoal being placed on the top of the tobacco; a flaming stick is never used. Two small sticks serve as tongs to take the bit of charcoal from the fire.

Water pipes are unknown, and I have not heard of any substitute for tobacco; as that plant grows in great profusion, I should not imagine that one would be required. The people smoke a great deal, but do not carry the practice to any injurious degree. Other narcotics are to the best of my belief unknown. A root, however, is sometimes chewed, which has the repute of exciting sexual passion.

Agriculture.—A large area of land is cultivated. After the forest has been cleared away by felling and burning, the ground is hoed. Hoeing and weeding are the only processes which it undergoes. There is no irrigation, but the soil is prepared for the seed as soon as the first rain falls, after which there is plenty of water. The land is usually marked out in long narrow strips by large stones placed at equal distances. Each man cultivates his own land; and if it is of considerable extent, and requires more hands than his family can give, he calls in the aid of his friends and neighbours. On such occasions no pay is given or expected, but all are ready to give and receive help in this way.

The hoeing is done by men, and the hoes used are made of iron with wooden handles. The process of weeding is delegated to the women, and there are three kinds of hoes used for the purpose. Sometimes they kneel down between the rows of corn, and use a

short one; or if standing, there are two other shapes employed. The two first kinds of hoe are made of wood and iron, the last solely of wood.

The married women always carry a knife in their girdles, which they use amongst other things for cutting corn. Its wooden handle is either carved or ornamented with iron. These implements are all of home manufacture, there being a good supply of iron in the country. The wooden handles are often ornamented, and differ much in shape. One very common shape I noticed was much that of a tortoise, but apparently there was no design in it; and no attempt seems made by these people to represent anything by carving, as obtains in other tribes.

Hammers and anvils are often made of iron, but stone ones are also used; there are no other stone implements.

The weeds are gathered together into little heaps, and left on the ground until it is prepared for seed again, when they are hoed in with the soil. Underwood is burnt on the field. Digging and mowing are dispensed with.

No animals are used in the cultivation of the soil.

Six months of the year are dry, and six months more or less rainy. At times the rains are very heavy. The corn is sown at the commencement of the rains, and some early kinds are reaped in fine periods between the rains. Most of the crops ripen and are reaped when the dry weather sets in. The soil is so fertile that two and three crops may be sown in one year.

There are four varieties of dhurra, besides dokn and telaboon, which are species of dhurra having very small grain. The seed of some of these kinds is mixed and sown together. An early and a late kind are sown in different rows in the same field. After the early sort (léli) has ripened and has been reaped, semsem is sown in its place, or sometimes the ground is planted with a kind of cucumber. A cereal called deli is sown in the gardens; its grain, however, is not eaten, but only kept for seed. The stems, which grow as high as 20 feet and about 2 inches in diameter, are sweet, and resemble sugar-cane. They are dried, peeled, and eaten uncooked; sometimes they are cut in small pieces, dried over the fire, ground, and mixed with semsem. Dokn stalks are dried in the huts, tied into bundles, and used as torches. The dhurra stalks are

used as food for the cattle, or made into baskets. Salt is also obtained from them. The women burn them to ashes, which are mixed with water and well boiled, the water is then skimmed, stirred, and boiled down, and the salt dried. Salt is also made from the root of a tree, from the stalk of a cereal (yobung) grown for the purpose, and some is also obtained from salt springs.

When the corn is ripe, the women cut it, and tie it into sheaves, laying the stalks in opposite directions. The men collect these bundles, and carry them on their heads to the "langas." These "langas" are frames constructed for the purpose of drying the corn. They consist of wooden poles placed at equal distances apart, and supporting cross beams of wood, which are again crossed by others. On this frame the sheaves are placed; they remain for about a month, and then the ears are removed to the granaries. When required for use, the corn is thrashed by women, who beat it with sticks over a basket. It is then winnowed. Dokn is thrashed in a different way; the ears are placed in a tall wooden tub, and beaten with a pole, much like our dollying. The corn is ground between two stones, like the Egyptian mohakka. One very large heavy stone is placed on the ground and chipped with a small one till it is flattened, then it is rubbed smooth with another stone, the process occupying two or three days. A small oval-shaped stone is used for grinding the corn upon the large one.

Land.—The acquisition of land appears to be an easy matter. It may be obtained from a neighbour by mutual arrangement, or by reclaiming it from forest or jungle. A piece of land once appropriated descends from father to son, and the chief of the tribe has no right to any but his own landed property. No definite boundaries exist to mark the limits of villages or districts; but a sort of indefinable understanding appears to obtain. Landmarks may be seen dividing strips of land owned by different people in one village; they consist of large stones placed at intervals of about 100 yards. Hedges are unknown, and no corresponding protection is found necessary to ward off wind.

Plots of land are protected from depredation by watchmen. Pits and traps are also made to catch elephants, buffaloes, and gazelles. These larger animals are, however, not so troublesome as ants and mice, which often eat the corn. It is also frequently injured by the intense heat of the sun, which shrivels it up before it is ripe.

Crops are grown on the same plot of land for several years running, and often twice in a year. When at last the produce yielded begins to degenerate, the ground is left fallow for a year or two.

Migrations are frequent, as the result of a discovery of good soil; sometimes a whole village will migrate to a new place. On such occasions the people may be seen flitting by small companies at a time, about ten men leaving at once, making a sufficient number to carry the wooden framework of the roof of a hut, which they take with them.

The only exportation consists in corn being sold or given to neighbouring tribes when they are suffering from bad crops.

Measurements of an Average Man.

No.		
1.	Height from ground to vertex,	161·5
2.	Greatest breadth from glabella backwards,	19·0
3.	Greatest breadth above ears,	14·7
4.	Length of face from root of nose to lower border of chin,	11·5
5.	Breadth of face from one foremost under edge of cheek-bone to other,	11·3
6.	Breadth of face from one angle of lower jaw to the other,	11·4
7.	Greatest breadth of zygomata,	12·
8.	Length of nose from root to junction of nose and upper lip,	4·7
9.	Height of head from chin to vertex,	21·2
10.	Length of neck from Adam's apple to sternal notch,	6·7
11.	Length of body from sternal notch to pubes (upper edge),	50·0
12.	Length of navel from ground,	99·5
13.	Length of upper edge of pubes from ground,	84·2
14.	Height of head from meatus auditorius to vertex,	11·8
15.	Distance between two ears at top of opening of meatus auditorius,	13·5
16.	Upper breadth of nose from one canthus to the other,	2·9
17.	Lower breadth of nose on cheeks,	4·3
18.	Length of nose from root to lip,	4·4
19.	Breadth of mouth,	5·2
20.	Distance from meatus auditorius to junction of nose and upper lip, middle line,	12·3
21.	Distance from meatus auditorius to root of nose,	13·7
22.	Distance from meatus auditorius to middle of upper lip,	14·8
23.	Distance from meatus auditorius to chin, lower edge, middle line,	14·5

No.		
24.	Greatest circumference of head at glabella,	54·5
25.	Arc from tragus to tragus over top of head,	34·0
26.	Circumference of chest just above mammæ,	84·6
27.	Distance between nipples,	20·1
28.	Breadth of shoulders across back,	34·7
29.	Circumference of waist at navel,	66·1
30.	Breadth of haunches,	27·9
31.	Length of arm from shoulder to tip of middle finger,	74·2
32.	Length of arm from shoulder to condylus external osis humeri,	30·5
33.	Length of arm from olicranon to end of ulna,	28·0
34.	Length of hand, wrist-joint to tip of middle finger,	19·4
35.	Length of leg from trochanter major to ground,	87·0
36.	Length of thigh from trochanter major to condylus external osis femoris,	41·2
37.	Length of leg from condylus external osis femoris to external edge of external malleolus,	41·2
38.	Length of foot from os calcis to tip of great toe,	24·6
39.	Arc from root of nose to union over head,	31·9
40.	Circumference of neck, maximum,	33·8
41.	Circumference of thigh, ,,	49·8
42.	Circumference of calf, ,,	35·3
43.	Circumference of arm, ,,	27·9
44.	Circumference of forearm, ,,	25·9
45.	Circumference of haunches, ,,	80·2
46.	Circumference of trochanter, ,,	
47.	Span of outstretched arms, ,,	155·7
48.	Span of thumb and mid finger,	17·3
49.	Length of thumb from second joint to tip,	3·5
50.	Greatest breadth of head from chin upwards and backwards,	24·0

Pulse, 68. Respirations, 20. Temperature, 97°·5. F.

Table of Principal Indices.

Cephalic Index.

$$\text{Measure } \frac{\text{No. } 3 \times 100}{\text{No. } 2} = 77{\cdot}91\,.$$

Nasal Index.

$$\text{Measure } \frac{\text{No. } 17 \times 100}{\text{No. } 8} = 91{\cdot}48\,.$$

Facial Index A.

$$\text{Measure } \frac{\text{No. } 4 \times 100}{\text{No. } 5} = 101{\cdot}7\,.$$

Facial Index B.

$$\text{Measure } \frac{\text{No. } 4 \times 100}{\text{No. } 6} = 100{\cdot}8 .$$

Facial Index C.

$$\text{Measure } \frac{\text{No. } 4 \times 100}{\text{No. } 7} = 92{\cdot}0 .$$

Skin dark brown. Iris brown. Conjunctivæ dirty orange-yellow. Palms and soles lighter shade of brown. Teeth good; none removed. Well nourished; not tattooed. Hair short, crisp, curly black. Slight down on upper lip, none on other parts of body. Not circumcised.

Eyes between 1 and 2 Broca's Table, only deeper. Darker when out of health.

Skin between 27 and 42, colour varies; but is lighter in shade than the hair, and has a more reddy hue.

Hair (41 Broca's Table).—The hair is extremely frizzly, fine in texture, and abundant, and grows in spiral tufts, the roots being equally distributed over the head, but thickest at the top. It appears to be capable of growing to a considerable length, its growth being favoured by a very free use of grease (without which it dries and comes out). The men allow their hair to grow about 6 inches, *i.e.*, when untwisted and measured. The women wear their hair rather longer, and with them the hair is trained to hang down; the men's, on the other hand, is more upright. When it has grown to these lengths they shave it entirely off. In shaving, some people leave a narrow ring of hair all round their heads like a crown; others leave three or four tufts, according to the tribal number; others again leave a great many small tufts growing. This is a fanciful arrangement, and has no particular signification.

Dyeing the hair is not practised. Baldness before old age is very uncommon. The hair is rather darker in colour than the skin; it turns grey about middle life. Only women practise the art of shaving; they make it a profession, and unite with it the extraction of teeth; the four upper and lower incisors being extracted from both sexes alike at puberty. A curved knife is used for shaving, the outer edge being sharp. Having placed the man's head in her lap, the barber proceeds to cut off the tufts of hair, she then squirts

milk from her own breast on to the scalp, rubs it well in, and applies the razor. Scissors are unknown. The eyebrows are also removed, as is all other hair found on the body. The hair from the upp lip and chin is often pulled out by the roots. Sometimes very old men will permit a few white hairs to grow on the chin. The women are paid for their services with an arrow.

Odour.—Notwithstanding their frequent ablutions, the Madis have an odour peculiarly their own. It cannot be said to be produced by dirty habits. It is always present, is varied by the oil and fat with which they anoint themselves, and is much intensified by muscular exertion, *e.g.*, running, carrying loads, &c.

Clothing.—The Madis do not wear any clothes, unless the word can be applied to a string which the women put round their waists, and from which hang a few leaves before and behind.

Physical Powers.—With regard to the physical powers of the Madis I can only give some very general notes, as I was not able to put their strength to the test with any amount of accuracy.

The following remarks will give some idea of their strength :—

They make admirable porters, being very careful of the loads entrusted to them, and display no little forethought and ingenuity in preserving them from injury. The rule is that no load should exceed 50 lb. in weight, and that it should be either square or oblong, the latter being preferred. They always carry the load on the head, on a pad made of grass, very rarely steadying it with the hand unless going over very rough ground. They strongly object to carry loads over 50 lbs.; but if pressed will take them up to 70 lbs., if the distance to be marched is not more than three days, and extra food is given them.

Loads of 100 or 120 lbs. are carried by two men, hung on a pole, which they balance on their heads ; but they do not like the work. If a very heavy load has to be carried, *e.g.*, a man, they place him on a native bed and carry him, two at a time, changing relays of men at about each mile. This they prefer to carrying by four men at once. I can testify from personal experience that it is far better to be carried by two men than four, for they go much more easily, and do not run against so many trees or overhanging branches. The relief men march before those who are bearers, and cry out when obstacles occur.

As regards distance, they carry loads of 50 lbs. 20 miles a day, for eight or ten consecutive days without showing signs of distress; but on the march they appear to require a great deal of water, and will sooner burden themselves with a gourd full than go without it for more than two hours at a time. If they go by a road where water is scarce, they generally take a few women or children with them to carry it. When they arrive at a stream, all loads are put down, and they bathe if the water is deep, or sit down and wash themselves if it be shallow, and then take a long drink. Europeans would probably prefer to drink *first!*

The Madis can scarcely ever be prevailed upon to march at night, even in bright moonlight, on account of bad roads, which is strange, as their eyesight is remarkably good. Neither will they start until the dew has disappeared from off the grass, or if made to do so by promises of reward they tie bunches of grass or skins before them, to avoid as much as possible being wet by the dew. In crossing a river of four or five feet deep, they stand in the water in a double row, and hand the loads from one to the other. Should the stream be very strong, they break down branches which have broad forks, and placing one end firmly in the bed of the stream, lean against the fork, and so get the needed support.

They march at a quick pace, but generally halt for 10 or 20 minutes after each three or four miles. Should heavy rain come on they like to stop and shelter themselves and their loads under quickly improvised shelters.

In carrying the Egyptian post these men make long and quick marches, 60 or 70 miles often being accomplished in twenty-four hours.

Pathology.—The Madis are a healthy race, and do not suffer very much sickness. Coughs occur during and after the rains, but very few people die of pulmonary complaints.

There are male and female doctors, but the males confine their practice to wounds, accidents, and snake bites, and do not receive payment, but have their food given to them when they are attending a case.

Wounds of the extremities heal very quickly. They are washed and covered up with a paste made from the roots of shrubs, ground and mixed with a little cold water. Scalp wounds give more trouble,

often suppurating, and at times causing death. Wounds of the chest are not much feared, but when they occur in the abdomen they are almost always fatal.

The people suffer from abscesses, which are opened, well washed with water, and then dressed with the above-mentioned paste.

Hydrocele is not as common as among neighbouring tribes. They try to cure it by long-continued pressure of the hands, but without much success.

The treatment of a broken arm or leg is noteworthy. When it is a simple fracture, the limb is pulled as straight as possible, and then sticks are placed as splints to keep it in position, and are tied with cords. When the bone is broken in pieces and the limb swells, so that they cannot properly straighten it, a number of small cuts are made, and cupping horns applied. These horns are made of cows' horns. If when the swelling has been reduced they still cannot straighten the limb, they cut the broken bones out, and fix on splints, applying a powdered root to the wound. Hæmorrhage is stopped by actual cautery. This operation is rarely successful, as most people who undergo it die in a few days.

The doctors impart their knowledge to young men, but their own sons do not follow their profession.

If a man is bitten by a snake, the wound is well sucked or the parts scarified, and cupping horns applied if handy, and then a powdered root is freely applied. This root is very expensive, a cow being often given in exchange for a small quantity of it.

Women doctors treat all cases besides those mentioned above, and receive one cow, two sheep, or a bundle of arrows for their services. They have but few medicines, and seem to make frequent use of magic. When a women doctor is called to visit a patient she brings with her a basket containing what I may call her magic wand. It is a kind of double tube about a foot long, each tube being about 4 inches in diameter. The one tube is partly filled with smal stones, the other is empty, to allow of the doctor performing her manipulations in it. This instrument is painted red, and oiled all over. The doctor shakes the wand, and mutters to herself for some little time, then feels the patient all over and draws her wand over him. When pain is complained of in the abdomen or chest, she first rubs the part with oil, and then places her wand over the

painful spot, introducing her hand into the empty tube. After working about for some time she at last draws out a substance which she calls the disease, taking care that the people shall not have any opportunity of seeing it closely. If pain is felt in the head, she cups the patient on the temples or nape of the neck by making small cuts with a sharp stone; an iron knife is not used. Cupping is also employed for very severe pain in other parts of the body.

These women doctors appear to be generally right in their prognosis. When their work is over they are always accompanied home by the head of the house (see *Odi* for the treatment of children).

Medicine is given internally for fevers, which are generally caught through bathing or getting wet after sunset. An infusion is made from a root after it has been dried and scraped, and this is drunk by the patient at frequent intervals. Profuse perspiration results after a few doses. Toothache occurs in old people, but only rarely are caries seen. They do not extract the tooth at once, but loosen it gradually by working it about a little each day until it comes out.

Epileptic fits would seem to be of rare occurrence, as I could not hear anything of them.

Small-pox occurs in epidemics; great numbers of the people die from it; and it is rare to see a person pitted, as only very strong constitutions recover. When a man is attacked by it, he is placed in a hut which has a sand floor, and a large fire is made in it to keep the patient very warm. Meat is never given him, and only a small quantity of food, such as thin porridge. When the pustules are well formed they are all opened with a thorn, and then an infusion of roots and leaves is given to the patient to drink twice a day.

The people are very particular to rub their bodies all over frequently with oil, for if this be neglected a scaly eruption results, which is, however, soon cured by an extra amount of oil.

As yet there is very little syphilis in the country, but it is gradually making its way from the north and east.

There are very few dwarfs; they are considered to be great curiosities, but are not ill-treated. Hunchbacks are more common, and occur in about equal proportions among men and women, so far as I could discover.

Marriage Customs.—The Madis are not allowed to marry amongst their own friends, but generally obtain wives from neighbouring villages. Just about the time when a young man arrives at puberty his father makes a tour of the surrounding villages in search of a suitable bride for his son. Having found one to his mind, he ties a twig of a certain tree round her wrist, usually the left one, and then seeks her father's permission for her to marry the youth. If the price to be paid in cows and sheep can be amicably settled, there is seldom any further difficulty in obtaining his consent.

If a young man meets a girl during his travels and she takes his fancy, he is at liberty to ask her to marry him, and if she is willing he ties a twig round her wrist. She then goes home and tells her mother what has taken place, and the mother informs the father, who sends for the young man, and if he approves of him, gives his consent to the union, at the same time stating the price he wants for his daughter. The young man has then to obtain his own father's permission. He tells him of his choice, and the price to be paid for her, and as a rule the father does not withhold his consent. The news is then published abroad that So-and-so's son is to marry So-and-so's daughter, and so much is to be the marriage portion. Should the parents not come to terms, the marriage does not take place, for the young people must always obey their parents in this matter, and runaway matches do not occur. Both young men and maidens appear to be faithful to their choice, and I have not been able to hear of a case of jilting.

Before the marriage takes place, the young man may go and see his fiancée whenever he likes. Meanwhile he works hard to get together as many cattle and as much grain as possible, to enable him to begin housekeeping. When he has passed the age of puberty by a year or so, the girl being also of a marriageable age, their friends are informed that the wedding will soon be celebrated.

The girl's father builds her a new hut, into which she goes a few days before the marriage ceremony takes place. The dancing ground is also swept and made ready.

The young man, on his part, collects together the cattle to be given for his bride. His friends all make him presents, the most substantial help coming from his father, mother, and father's brothers. The payment must be made in cows of one year old, or

bulls of two or three years, also one one-year-old fat cow as an extra gift for the feast to take place at the bride's village.

On the morning of the day on which the ceremonies are to begin, a band of youths proceed from the bride's village to the bridegroom, who hands over to them the stipulated number of cattle. Each youth leads one cow by a rope tied to its leg, its neck being ornamented by a garland of leaves. Thus they are taken to the bride's father. A group of unmarried girls, from the bridegroom's village, accompany the youths, and the bridegroom's brothers and sisters make up the party. Should he be an only child, two of his best friends or unmarried relations join the band. He himself remains behind. On their arrival the cattle are counted before the bride's hut, and if found correct as to number and quality, as is usually the case, they are sent to the cattle pen, but are not mixed with cattle belonging to the bride's father, which are previously removed to a distance. Should the tale not be correct, a messenger is sent to the bridegroom's village, if it be near, to fetch the remainder; but if at a distance, the ceremonies are delayed a day, or may be more. This mishap, however, rarely happens, as care is taken by the bride's father that the right number of youths are sent, and the bridegroom is particular to provide the corresponding number of cows, so that mistakes are usually avoided.

The fatted cow is killed by the bridegroom's brothers in front of the bride's hut, and their cooking operations commence and a great feast is held, after which dancing takes place. Very often nothing but water is drunk at the feast; and if beer is provided it very rarely, if ever, leads to drunkenness. During the feast and subsequent dancing, which lasts two days, the bride is not allowed to leave her hut; but she is not left quite alone, as her future brothers and sisters-in-law keep her company, and expatiate meanwhile on the virtues of her future husband, and the delights of married life. They also fetch her food, but retire while she eats, as it is not proper for them to see her at her meals.

On the third day there is another feast, on which occasion the bride's father provides the cow, and dancing follows as before. Then the bride, for the first time, leaves her hut, and goes to the dancing ground, accompanied by her brothers-in-law, who walk one before and one behind her. They proceed to the centre of the dancing

ground, round which an assembly of spectators sit or stand under the shade of the trees. The brothers-in-law then retire to a short distance from the bride ; she is welcomed by a loud shout, and then begins to dance the particular marriage step, which lasts a long time, and is accompanied by special music and clapping of hands. The longer she keeps on dancing the more creditable it is to her. It is a proud time to the lady, and she takes great pains to show off well, and to please the spectators. Afterwards she retires to her hut, and word is sent to her bridegroom that she has acquitted herself well. The next day she rests after her tiring exertions, and the day following the bridegroom arrives, attended by his unmarried friends of both sexes, relieves his brothers of their charge, enters the hut, and claims his bride.

The happy pair remain eight or ten days together in that village, being supplied with food by friends, who also fetch them water and firewood, in order to save them trouble. During this time the father of the bridegroom is engaged in constructing for his son a new hut, and on the eighth or tenth day the newly-married couple come and pay a visit to it. A sheep is killed at the door, after which they enter over the body and blood of the animal. The bride is then only presented to her father and mother-in-law, and remains there two days, but never eats in the presence of her husband's parents. The young couple return to the lady's village, re-occupy her hut, and remain there a variable time—until, in fact, the lady is in an interesting condition. As soon as this occurs, they return to the husband's hut, and settle down to their usual pursuits.

Divorce is not common, and if a woman is barren it rarely occurs. It may, however, take place if a wife makes herself disagreeable to her husband, friends, and relations, and also if she should prove unfaithful; but this is a rare occurrence. Should divorce take place for any just cause, the wife is sent back to her father, and he refunds the greater part of the cattle, the number varying according to circumstances.

If a wife wishes to visit her friends or relations at a distance, her husband accompanies her, and fetches her back at the end of the visit.

Polygamy is permitted, but is not very common, and seems to be regulated more by a man's wealth than anything else. The greatest number of wives allowed appears to be four, and a long

period (two years?) elapses between each new marriage. Each wife has a separate hut, and the husband passes a definite number of days with each in rotation. This is regulated as circumstances may require, but each wife expects her full allowance. When this is granted, as it usually is, the wives live on good terms with one another.

Should a woman who has a child be divorced, if the divorce has been for her adultery, after the child is weaned it belongs to the husband; but if she should be divorced from any other cause, she keeps the child. In either case, the father and mother can visit the child, or it may go on a visit for a few weeks to either parent. Women who have been divorced may, but seldom do, marry again; should they do so, they are to be had cheap, and the children, if there be any, from the previous marriage remain with the grandfather. The Madi women generally make very good wives, and married life is apparently a smooth one. Prostitution in a general sense is unknown. Before marriage the girls are very carefully looked after, but as marriage usually takes place very early, there is not much cause for them to go wrong. This also applies to the men.

Reproduction and Birth, &c.—Early marriages appear to be the rule, and, as before mentioned, polygamy obtains only to a limited extent. It is very difficult to give facts as regards the number of children born, &c., but a few notes may be of interest.

Four children would seem to be a fair average family. Few die directly after birth. Twins occur at times, and are considered very lucky both to the parents and to the village at which they are born. Many congratulations are offered, but no special ceremonies take place at their birth. I could not hear of a single case of triplets, but one woman was said to have had four children at a birth. Girls and boys are equally valued, but a boy is generally preferred as the first child.

As a rule, labours are very easy. As soon as a woman thinks that she is near her time of delivery, she abstains from meat, but eats a good deal of vegetable food. She gets a neighbour to help to clear out her hut, sends her children, should she have any, to friends, and when labour commences, she walks round her hut, while her friends place a deep layer of dry sand at a short distance from the door. Sometimes two good-sized stakes are driven into the ground, about

$2\frac{1}{2}$ feet apart; and the sand is banked up near them. The woman then sits down on a skin placed on the sand, puts her feet up against the stakes, and clasps her ankles with her hands, her arms being inside the knees. Her friends take it in turn to support her back, and at times aid her by pressing or rubbing the abdomen. Another friend squats down before her to receive the child as soon as born. The sand, of course, moulds itself to the woman's body, and being pushed down in front, might almost be said to support the perinæum. A fire is kept burning in the hut, and a very thin porridge is given the woman at short intervals. She keeps remarkably quiet, and often never moves from her first position until after the child is born, her friends keeping up all the time a low kind of chant, and doing all they can to encourage her. When the child is born, the cord is cut by a stone knife as a rule, but sometimes it is bitten. Should the cord bleed, the woman who has received the child takes the cord in her mouth and squeezes it with her teeth, so stopping all hæmorrhage. They never tie the cord. The placenta is buried in a hole dug outside the hut—that of the boys on one side, that of girls on the other. Still births are very rare.

When all is over, the mother is gently moved to the side of the fire, where she lies down on a bed made of dried grass covered with a skin. As soon as the child is born, it is cleaned by gentle rubbing, and then smeared with oil and wrapped up in a soft skin, after which it is shown to its father, grandfather, and other friends. In about an hour after birth it is put to the breast. The mother gets about again in three or four days. She then sits with her child in the door of her hut, and receives the congratulations of her friends. The woman is not allowed to eat meat for about a week after her confinement.

On the occasion of a child's name being given it, a fowl is killed by the father and grandfather before assembled friends. They cut off the animal's head, apply some of the blood to the child, and pronounce the name. It is not at all uncommon for children to be named according to the season in which they are born—*e.g.*, Kranobu = famine; Kradaru = hunting season. At other times they are called after their deceased relations, rarely after living ones. Family names do not obtain, but a son bears his father's name in addition to his own; more frequently, however, pet names are used.

In this district women do at times bring forth their children on the march, and then continue marching; but this is by no means a frequent occurrence, and is guarded against as much as possible. I have known it happen on two or three occasions, but the result in one case was fatal to the mother.

When a hard labour occurs, and a woman remains a long time undelivered, so that her strength begins to give way, a man is sent for to deliver the child. He, however, uses no instruments; and should he fail, which, I am told, hardly ever happens, mother and child as a rule perish, for abdominal section is not practised here. Barren women are uncommon. Very few births occur out of wedlock, but I was not able to obtain much information on that point.

The women suckle their children about two years, but the period of their separation from their husband is only six or eight months. If several mothers are suckling at the same time, it is not uncommon for them to suckle each other's children; and I have once or twice seen a small child, who did not find sufficient milk in his own mother's breasts, toddle off to another sitting by and commence to suck away without rebuff. During lactation the breasts are of an unusually large size. After several children have been born they become very flabby, and hang down like long flaps of skin. A cord is then tied round the chest to prevent them flapping about and causing inconvenience.

When born, the babies are of a reddish tinge, and they get dark gradually. The women carry their infants in skins which have been dried in the sun and scraped clean and smooth with a stone, and softened with butter. The skins of goats, gazelles, sheep, and calves are used, the legs being tied together and strung over the mother's shoulders. The baby is placed in the skin under the woman's arm, with its head behind. Sometimes a gourd is placed over the head to protect it from the sun. When older the child is carried on the arm. Infanticide is unknown.

Education of Children.—A good deal of attention is paid to the instruction of children in matters of conduct. They are taught to behave well at meals, not to put their hands into the dish till after their elders have helped themselves, to rise as soon as finished, and having washed their hands, to remove to a little distance. They

are also taught to be quiet when older persons are holding a council or chat. They are made to salute people in passing, and to show kindness to the aged and to the sick.

The girls are taught to cook, to sweep out the huts (with bundles of fine dried grass), to show hospitality to strangers, to fetch water and firewood, to elude arrows at a fight, to dance, and to perform "Ionian" movements. The boys are taught to shoot, to fight (blunt arrows being used), the proper way to treat an enemy, &c.

The education of boys and girls is not considered to be complete until they have travelled. When about ten years of age they are sent away from home to visit friends and relations at distant villages or among neighbouring tribes. They remain away during the fine months of the year. The girls may return at any time, but the boys are usually anxious to remain away as long as possible, in order to learn as much as they can from contact with other people. Should the girls wish to come home, the boys will bring them, and as soon as they have seen them safe with their relations, they start off again. The boys must, however, return home when the rains begin, and remain during the wet months, to help their fathers in agricultural work; whereas the girls, if they choose, may stay away; if wanted, they are sent for. When out on these visits the young people take part in the hunts, dances, or whatever else may be going on. Sometimes a father will take his children a round of visits.

Both boys and girls are taught to find their way about, so that if the path should be lost they are not long in discovering their whereabouts.

Family Gatherings.—There does not appear to be any special occasion for family gatherings, but from time to time all the sons, daughters, and grandchildren meet at the father's house. The love for children causes great interest to be expressed about the babies. At such family gatherings the father directs the thoughts of all to grandparents and old friends who have passed away, enforcing at the same time the duty of attention and care to relatives and friends when ill, and of mourning for them when dead, as they then are beyond the reach of help.

Tribal Signs.—Each division of the tribe has a number, by which those who belong to it are known. Persons are said to carry so

many stones, but this is merely a form of speech, as the stones are not literally carried. The lumps of earth thrown into a man's grave correspond to his number of tribal stones, and in this way also will a man often regulate the number of tufts of hair to be left on his head after shaving.

Burial Customs.—Immediately it is known that a man is fatally wounded, the news is sent to his wife, who hastens to him, taking their children with her. A touching scene is witnessed when they reach the dying father. The little children are placed upon his knee, and the others stand round about him, while he gives them his "blessing" by putting his hands on their head and moving his mouth as if spitting. After telling them to be good, and not to grieve too much for him, he solemnly addresses his eldest son, giving into his charge his mother, brothers and sisters; also the fields and cows. He also is careful to tell him through what tribe he has met with death, in order that his son may some day revenge him by killing one or two men of that tribe. Then follows an affecting farewell to his wife. If he is a well-known man, and not far from his home, a great company of his friends and acquaintances gather round to take leave of him. While the body is being carried to his hut, a drum is sounded as an intimation that he is dead. This is also done at the hut if a man dies at home, and is repeated at the burial. The body is usually buried one day after death, close by the man's hut, but sometimes by his father's.

A deep round hole is made in the ground, and at the bottom of this a deep recess is scooped out. In this recess the corpse is placed, being laid on the right side with the head leaning on the right hand. Lumps of earth are then thrown into the hole by the children, first with their backs towards it, and then their faces, the number of lumps coinciding with the number by which the deceased's tribe is known, the girls throwing one less each time than the boys. A pole or tree trunk is then fixed in the ground at the bottom of the hole, which is not filled up, but covered by two large stones placed against the pole. Sometimes there is no pole, if a stone can be found large enough to cover the hole. Over this is erected a conical mound of earth, three or four feet high, which is stabbed by flat stones. If a pole has been placed in the grave it projects above this mound, and is surmounted by the horns of cows killed by the

grave. Four cows are killed by the friends out of respect for the departed, and the eldest son often kills his favourite ox.

If a great man has died, friends and relations come from a distance to the burial, and stay a few weeks (four?) mourning for the dead. For the first four nights they sleep on skins by the grave, and during the remainder of the time they pay frequent visits to it and make lamentations. The deceased's widow resigns all household duties to a sister or friend, and gives herself up to weeping during a month.

At the end of this time a lamb is killed; it is subsequently eaten by the friends, as were the cows killed on the day of burial. The son leads the lamb to the grave, but it is killed by a man of a semi-priestly order (whose office it is to perform such like duties on various occasions). This man, after killing the animal, sprinkles its blood on the people and the grave. After speaking at length on the virtues of the deceased, he sprinkles the people with water, exhorts them to put away their sorrow, and to show kindness towards each other. The friends then take their leave, but a year after the man's death all his relations and friends who live near meet again and celebrate the day by a feast and dance; and on these occasions the dance is never followed by a fight.

If a woman die her friends mourn her loss also for a month, but for children the time of mourning is only a few days.

If a man should be killed at a fight or hunt, and the place and manner of his death be unknown, his friends go and search for his body, and if they cannot identify it, they bury any bones they may find about the place of supposed death.

As soon as the period of mourning for a father is over, the children (if young) are taken to their father's family, and a consultation is held as to what is the best thing to be done with them. They are usually placed inside the circle of consulting relations, and if old enough are asked whether they will stay and live with their father's people, or go with their mother. The mother is urged to remain in the village, but she usually prefers to go to her own relations, and as a rule the children go with her. Sometimes the eldest son, if he is old enough, will remain on his late father's property and look after it, the mother with the rest of the children going, for a time at least, to live with one of her brothers. Later

on she may return to her old home, or more rarely still she never leaves it.

Treatment of Superiors.—There appear to be no rules of precedence nor any difference in the treatment of rich and poor. The poor are generally those whose parents have died when they were young, or those whose father's cows have been stolen by an enemy. In this case the children are adopted by relations, and when they marry, a small number of cows are given to them as presents to start them in life.

Each village is quite independent, having a president or sub-chief at its head; only in time of war must the men from each village assemble, under the head chief, who resides in the largest town. The village head-men and even the chiefs are treated with great familiarity, no spirit of subjection or fear apparently existing.

Hospitality.—Hospitality is inculcated and universally practised to kinsfolk, neighbours, strangers and enemies.

A passer-by is invariably invited to share any meal which is proceeding, and a refusal to partake of the proffered kindness is considered as an offence. If he is in a hurry, and does not wish to be delayed, politeness requires him to dip his hand in the dish and to eat a mouthful before proceeding on his way. At a meal the guests sit on the ground, and help themselves out of the common dish. Water is brought them to wash their hands, children performing this duty. Water is always at hand to offer to passing travellers. Every family has a hut for the special use of visitors, and if guests arrive unexpectedly when the hut is already occupied, the children are turned out to sleep at a neighbour's, and their hut appropriated to the visitors.

Treatment of Women.—Women are treated with respect and politeness by the men, who always show them preference, resigning to their use the best places, and paying them such like courtesies. They eat at the same time, though not out of the same dish as the men; but associate with them on equal terms, being consulted and honoured. Any insult to a woman is revenged, and is frequently the cause of war. Drunkenness is very little known, but in the case of a man becoming intoxicated, and in that condition insulting a woman, he is punished by being tied up until perfectly sober.

Treatment of the Aged and Infirm.—In the training of children, obedience and great respect for parents and elders are inculcated.

Great care and attention are paid to the aged, and counsel and teaching from them is considered of special value. The sick and infirm are cared for and nursed with much solicitude. Much affectionate care is exhibited by husbands to their sick wives.

Communications.—The construction of the roads is very simple, a track of some two feet wide being formed by merely cutting down the underwood of the forest. More than this is not attempted; a network of small paths in the forest being made by use. Swamps are usually passed by wading, although occasionally a way across them is made by filling in with stones, sticks, and grass.

Rivers are crossed by swimming, an art which is learnt very early, as is also an acquaintance with the haunts of crocodiles and hippopotami and the shallow parts of the rivers, so that should a man be carried down by a swift current he is quite at home, and knows where best to make for land. Boats and even rafts are unknown, but bridges are occasionally constructed over rivers, and are made as follows :—Trunks of trees are firmly fixed in the bed of a river in the dry season, being supported by stones, and having forked tops along which is laid a single row of logs—thus forming a simple kind of bridge.

No accommodation is provided for travellers between villages; they rest where rivers or wells supply them with water, and then continue their journey till a village is reached.

On a journey, if a man cannot find a stream, he digs for water in the ground; and the wells thus formed last for a time, and serve for the use of other travellers.

When a village is reached there is no lack of accommodation, hospitality being universally shown alike to friends and enemies. Immediately a stranger is seen, he is asked how many stones he carries (see *Tribal Signs*). If the man who accosts him is of the same number, they fraternise directly; but in any case, the stranger is escorted round the place to see all there is to be seen, and a hut and food are given him.

No vehicles of any description are used, the only mode of conveying persons who are too old or too ill to walk is by means of a kind of litter made of branches laid side by side, and fastened together on to cross pieces of wood. Upon this rude contrivance the individual lies or sits, and is carried by two or four men.

Horses are not known, nor are any animals used as beasts of burden; but their need is little felt, as the necessaries of life are very few. Heavy weights, such as animals or fish, are often slung on a pole, and carried between two men ; while trunks of trees are transported by the simultaneous efforts of men, pulling to the sound of their voices.

It is customary for meeting travellers to exchange greetings, a phrase answering to our "How do you do" beginning the conversation. The young are carefully instructed by their elders to show a friendly spirit even towards an enemy if met on the road, unless he should appear to be bent on insolence, in which case high words are to be returned, and they are frequently followed by violence.

It is not necessary to obtain permission before passing through the territory of another tribe; and even if travelling among a hostile tribe, a man is unmolested unless he himself provokes attack.

When a man encounters a stranger on the road and is accosted by him, he stands in the usual position of ease (the right foot resting on the left calf), with his bow and arrows in the left hand, and talks to him in a friendly manner, at the same time on the watch for lurking enemies. If the traveller prove to belong to a hostile tribe, and become insolent, the pleasant tone must not be maintained (it would be taken for cowardice or fear), but he must be met with "flashing eyes and angry expostulation;" should he wax more angry, and use insulting language about the man's mother, a fight is unavoidable. In this case it is possible that others (friends of the stranger) will be in ambush near, and at a given signal will surround the man, so that for a long time he must try by great agility to avoid their arrows. There is a leaf which is believed to possess peculiar virtue, and if any of it is at hand the man will endeavour to seize some of the leaves and rub himself with them. He then aims at the stranger who accosted him, and if possible shoots him. If he is successful in killing his assailant, he may escape if he please; but to do this is considered a disgrace unless he has killed his enemy, or at least one of his tribe. Should the man be completely outnumbered, but contrive to escape, he summons assistance by means of his horn, and then, reinforced by others, returns to the scene of conflict, and should the enemy still be there, the fight is renewed.

It is usual for young persons to travel over the surrounding country often to considerable distances, and thus they acquire a practical knowledge of the country, and without the help of mile-stones, sign-posts, or other landmarks (all of which are unknown), they become expert in finding the way from place to place.

Salutations.—The modes of salutation coincide almost exactly with our own—greeting being expressed by shaking of the hand and kissing. Members of a family kiss, but the boys shake hands with their father and each other. Husbands kiss their wives and female relations, and friends kiss each other. Matutinal greetings are usual. Great joy is manifested at the return of a member of a family from a long absence, the brothers and sisters running out to welcome him; and frequently a lamb is killed as an expression of joy, and great virtue is believed to be in the blood, some of which is put upon the returned traveller.

Swimming.—Swimming is practised by both men and women in the Madi tribe, and the art is acquired very early in life. It is put to practical use by crossing rivers, fishing, &c. They do not take a header into the water, but simply walk or jump in. Diving is not practised. They swim as a rule hand over hand, and splash about and make as much noise as possible to frighten away crocodiles. Sometimes they carry children on their backs when in the water. They have a habit of taking in mouthfuls of water and spitting it out forcibly when in the act of making a stroke. On coming out of the water they rub themselves all over with their hands, to get rid of as much water as possible. If near home they rub themselves with oil after bathing.

Bathing and Cleanliness.—The Madis bathe each day in a river or other water near their homes; small children wash themselves at home in large earthenware jars. No soap is used or any substitute for it. They have no sponges. They always rub oil over their bodies after each bath. When they cut their nails, they bury the parings in the ground.

Division of Labour.—In the division of labour the woman's sphere is at home. She may help at times in the lighter field work in the cool of the morning, but must return home before the middle of the day, the men continuing at work. If, however, a woman has a family of young children to look after, she seldom leaves home at

all. Her duties are domestic; she lights the fire, sweeps out the huts, fetches water twice a day from the river or well, makes butter, stores the food in jars, and cooks, &c. Children are early taught to be useful in helping their mother; and should she be ill, the husband fetches the water, lights the fire, and a neighbour is called in for aid, as the father cannot cook. No one is paid for such services any fixed price, but some present is as a rule given. The women attend sick persons with much solicitude.

The man's work consists in hunting, fishing, agriculture, procuring wood for bows and arrows, and firewood. He partly makes the bows, milks the cows, and sometimes helps in making the butter. The men also build the huts. When removing from one place to another the men carry all the heavy things, as well as the roofs of the huts, and fix them before they fetch the women. In hunting expeditions the women carry water in small jars for their husbands.

Religion.—With regard to the religious beliefs of the people, I have not been able to ascertain much, their ideas being so vague that a much longer sojourn among them than I made would be necessary to discover what is really or partially believed by them. They appear to have an undefined belief in a great Being who made the world and men. They also believe in "isa" = the soul or thinking part of man, which however perishes with his body. There is no belief in a resurrection or after life for man, though ideas and speculations on the subject are indulged in.

The first man is said to have come from the sky, but departed friends are thought of as being under ground, and their bodies are thought to turn into white ants, or to grow up as grass, mushrooms, &c.

I have been told that sometimes people imagine they hear their departed friends speaking to them, and that when they look to see the familiar forms nothing is visible but smoke. When this happens there is a general lamentation among the friends of the departed, and a lamb is killed and its blood is sprinkled on them all.

One man, tradition says, dreamt that his "isa" (soul) left his body sleeping, and went up to the sky. It is a common thing for lost friends to be seen in dreams, and to seem to turn into lions or some other object of terror. However vague their notions of a Deity or of themselves as spiritual beings may be, they teach and practise very sound principles of good.

A *good* man to them is one who is brave and not afraid to fight or die, who seeks the welfare of others, and is always ready to show kindness to them, who respects the aged, helps the sick and infirm, and gives to those who are in need.

Superstitions.—Among the superstitious practices in vogue in the Madi tribe, is the detection of guilt by ordeal.

Three means of trial by ordeal are used, through which it is believed guilt can be detected. If a man is accused of an offence and denies it, he goes with his accuser to have the matter settled by ordeal.

In one mode of trial they both receive a red feather of great value, and have to bite it through. This is considered very dangerous, for after a few weeks the guilty one will fall ill and die. Unless very sure of their own innocency they rarely try this ordeal.

At other times seed is given to be eaten, which will be innocuous to the innocent, but fatal to the guilty. Another method is by throwing down small sticks of equal lengths. In the case of an innocent man, the sticks will fall against each other, standing up like the legs of a Gipsy table, whereas a guilty man's sticks fall flat. Before any of these trials the men look up and solemnly invoke some invisible being to punish him if guilty, or help him if innocent.

If a man is seen committing an injury and does not deny it, the injured person challenges him, and they fight until one is killed or badly wounded. Sometimes the men of the village come together and separate them, and then a kind of rough trial takes place, and the defaulter is obliged to make restitution in kind, *e.g.*, a cow and a goat for a cow injured, a hut and a cow for a hut, &c.

There are three classes of men who possess authority in villages and districts. Class A. preside over ordeals; class B. possess the power to try persons accused of murder or any great crime; and class C., perhaps the most important of all, consists of the men who kill the lambs on particular occasions, as described elsewhere.

Madmen are always hanged. If birds afterwards feed on the body, it is taken as a proof that the person was really mad, their absence showing that he was wrongly put to death.

Great faith is placed in the power of a certain plant, a piece of which, after being spit upon, is applied to a man's shoulders and

legs, and is believed to strengthen him, to preserve him from danger, to make his enemy "see crooked," or to enable him to slip out of his hand, just as the stem of the plant slips like soap when it is grasped. With this idea mothers frequently apply this plant to their sons. Sometimes also they sprinkle the boys with water, with a similar notion.

Omens are believed in. One of the most common is sneezing; it appears to forebode good or evil, according to what is being said at the time, producing a contrary effect to what is expected. Tripping one's foot against any thing is considered ominous. To trip on the same foot twice on the same day is a bad sign, once on each foot is a good one. Some people consider one of their feet lucky, one unlucky. It is thought to be unlucky to return by the same road that a man goes by, both for long journeys and short walks; a different route is always chosen when possible.

Odi.—There appears to be a belief in the existence of elves or spirits, though this would seem to be an invention of the female doctors to gain a hold on the people. "Odi" is the name by which these beings are known. They are supposed to live underground, and their help is sought in cases of illness among children.

If a child is ill, the lady doctor first examines it, and then retires to a quiet spot at a distance from the hut, where she erects a miniature hut of sticks and grass. She is followed to this place by the mother and one of her little boys, laden with a pot of food and a live fowl. She then proceeds to invoke the Odi to appear, but often gives out that they cannot come till the next day, being busy. At last they make their appearance inside the small hut, but are visible to none but the doctor, others only hearing them speak. Two usually appear, a male and a female, more than that number refusing to come at once. The doctor says they have human faces and serpent's bodies. She pretends to give them food to eat out of the pot, and asks their aid towards the sick child's recovery, shaking all this time her magic wand or rattle. When they have had enough food they vanish, and the doctor falls down right over the small hut. She strikes the ground with her hand, and appears to have a fit, unconsciousness lasting a few minutes. Before falling she tells the mother and boy to run home as fast as possible, and shut the door. A strong women is always present at this incanta-

tion, who is ready to raise the fallen doctor, and give her water to drink. After she has recovered from her real or supposed exhaustion, she is supported to the sick child's hut to see her patient. Before the door is opened a certain formula is gone through, after which she enters the huts, feels the child all over, and gives her opinion as to whether it will get well or not. She is then escorted home by the father, who takes with him her fee, in the shape of a goat, cow, or arrows.

The Custom of Killing a Lamb.—A remarkable custom is observed at stated times—once a year, I am led to believe. I have not been able to ascertain what exact meaning is attached to it. It appears, however, to relieve the people's minds, for beforehand they evince much sadness, and seem very joyful when the ceremony is duly accomplished.

The following is what takes place :—A large concourse of people of all ages assemble, and sit down round a circle of stones, which is erected by the side of a road (really a narrow path). A very choice lamb is then fetched by a boy, who leads it four times round the assembled people. As it passes they pluck off little bits of its fleece and place them in their hair, or on to some other part of their body. The lamb is then led up to the stones, and there killed by a man belonging to a kind of priestly order, who takes some of the blood and sprinkles it four times over the people. He then applies it individually. On the children he makes a small ring of blood over the lower end of the breast bone, on women and girls he makes a mark above the breasts, and the men he touches on each shoulder. He then proceeds to explain the ceremony, and to exhort the people to show kindness, for example—

If rich, not to deny a cow or sheep to a poor man that asks one. If eating, not to appear unaware of a passer-by, but invite him to share in the meal. If children see a stranger, they should run to their mother for water to offer to him ; or if they see an old woman fall, they should not laugh, but give her assistance.

When this discourse, which is at times of great length, is over, the people rise, each places a leaf on or by the circle of stones, and then they depart with signs of great joy. The lamb's skull is hung on a tree near the stones, and its flesh is eaten by the poor. This ceremony is observed on a small scale at other times. If a family is in

any great trouble, through illness or bereavement, their friends and neighbours come together and a lamb is killed; this is thought to avert further evil. The same custom prevails at the grave of departed friends, and also on joyful occasions, such as the return of a son home after a very prolonged absence.

Harvest Feasts.—A harvest feast is held as soon as the corn has been reaped and placed on the "langas" to dry. It is then too that the general holiday time commences; there is very little work done from this period until the rains begin, hunting, dancing, and fighting occupying the interval.

The harvest feast is held in each village, and is only attended by the inhabitants of the place. It takes place on the open space which is usually found in the centre of the village. At the conclusion of the feast speeches are made. It appears that one man presides, and after an opening speech by this president, women as well as men address the company. The old people are listened to with great respect, and give advice to the young. The belle of the village is reserved to make the last speech, after which all disperse.

The enthusiasm evoked by a favourite orator or palatable sentiment is expressed by clapping of hands; but weariness or impatience is merely shown by sullen looks, only those who are rude covering their faces with their hands.

Music.—The Madis are very fond of music, and have several kinds of musical instruments—drums, harps, horns, and flutes.

There are large and small drums. The small ones are made out of a tree, the trunk of which is more than a foot in diameter, and their length varies from 2 to 3½ feet. The block of wood is either hollowed out by fire, or more rarely by the knife. Pithon or goat skin is usually fixed over one end by means of wooden pegs. Sometimes, however, both ends are covered, and then the skins are caught together by long laces of hide. The larger drums are very different both as regards size and shape. Logs of wood about 12 feet long are hollowed out, and placed on four wooden legs, four handles also being cut out of the wood (see fig. 13). A narrow opening is left along the under surface of the block, and not covered in. The drum is beaten by large sticks, having a somewhat globular end. All drums are well warmed before use, and near the larger one a fire is kept burning during its use.

The harps are made as follows:—The half of a large gourd is taken and two round holes made in it, into which are fitted two upright sticks, which diverge a little from each other. They are united above by a cross bar, from which strings made of sinews or fibres are carried down, and passed through small holes made in the gourd, on the inside of which they are fastened to small bits of wood. When in use the gourd is placed against the belly of the player, and so acts as a kind of sounding board.

The flutes are made out of hollow canes, having eight holes and a mouth hole. They are held as in Europe. They also use rattles made of gourds, partly filled with dried dhurra or small stones. Small bows are used as musical instruments. They are strung with hair from a giraffe's tail; one end of the bow is placed against the teeth, and then the string is struck with a switch.

I fear it is beyond my power to describe the music produced by these instruments, but I can testify that on a moonlight night the melodies they give forth are very weird and yet sweet, and at times fantastic.

Dances.—The harvest feast is usually followed the next day by a dance—this being the first dance of the season. One of the larger villages is chosen as the scene of the dancing festivities, which are held in a large open space outside the village. Great numbers of people assemble from the surrounding country; and as most of the inhabitants have to be present on these occasions, often only the old and very young people are left behind in a village. The holiday makers are accompanied by their cows, and these are left to graze outside in the forest, boys remaining in charge of them. This is done as a precaution, for if the cattle were left unprotected, raids might be made on them by enemies.

The band consists of a large drum and several small ones suspended on a pole; horns and rattles are also used. The musicians are placed in the centre of the ground, being encircled by the dancers. The old people present stand round the ground, and clap their hands in time to the music. The young men are grouped together and the young women placed opposite them. The married women dance together, and the married men in a group by themselves.

The dancing is chiefly from side to side, not forwards. Some-

tin. s, however, a young woman dances across, and invites a young man to advance into the centre and perform a *pas seul;* and when he has finished, he in his turn asks a young woman to exhibit her skill, but they do not dance together. The men paint themselves with various colours for these occasions, and the women are adorned with brass necklaces, rings on their waists, arms, and ankles, and flowers round their necks.

Fights.—These dances are usually ended with a fight; in fact, it seems that the dance would not be supposed to have gone off properly without some such finale. The fight is begun in this way: A man shoots an arrow high in the air, so that it falls among the dancers, who immediately cease dancing, and range themselves into different sides, according as is their division of tribe. Then the game begins by a shower of arrows. The women remain with the men, carefully eluding the arrows; should a man be hit, some of his female relations rush up to him, carry him to a place of safety, and wash his wound. They do not try and stop the bleeding, for fear of causing inflammation. Should inflammation occur, light incisions are made to allow the blood to run freely. A special knife is used for this purpose. Should a woman be killed, there is great excitement, and the fighting becomes desperate. War goes on between the tribal divisions, until the offending one is considered to be sufficiently punished, and pays a large indemnity in cows. If no fighting is desired at the dances, all the bows and arrows are hidden.

Boys are early taught by their fathers the art of war, especially how to elude an enemy's arrow. This requires great dexterity and much practice, and young children are trained from very early days, shooting at their father with blunt arrows. The young men also instruct large classes of boys, and mothers train their daughters in the art of eluding arrows.

As in Europe, women at times take a dislike to one another, and very occasionally even come to blows. If they do, a very fierce and bloody encounter takes place, for the women, before fighting, put on iron bracelets with spikes both straight and curved projecting from them; with these they tear one another very badly. The Arab slave dealers do not appreciate these bracelets, and when in their raids they see a woman with them on, she is generally shot down at once, for at close quarters the Arabs are no match for them.

Weapons.—The weapons employed in hunting are bows, arrows, and spears; arrow heads have various shapes.

Arrows.—The heads are made of iron, and are barbed and ornamented. Sometimes they are poisoned for killing lions, &c.

The shafts of the arrows have a hole made at the top by a red-hot iron; into this the head is fitted and kept in place by flat iron wire; similar wire is also used to ornament the shaft. The arrows are notched, but have no feathers. The arrows used in war are made of the hard wood of the "pi" tree. The barb is also made of wood sharpened at both ends and fitted into the shaft. The end of the shaft is bound round with red string to prevent it splitting. In withdrawing the arrow from a wound the head is left behind.

Spear Heads.—These do not vary much in shape, but different sizes are made. Very large heads are used for elephants. The women, if on a long journey, carry small spears with ornamented handles. The spear shafts are tipped with an iron spike; both heads and spikes have a hole made in them, through which iron wire is passed to fasten them firmly to the shaft. No blunt-headed arrows are used, save those employed to instruct the children.

When hunting or fighting, the left hand is protected by a woven string "gauntlet"; it covers the palm of the hand and fingers, the thumb being left free.

Bows are made of several species of wood. The strings are formed of twisted tendons. Sometimes the bows are made quite plain, others are ornamented by rings of crocodile skin, but the middle of the bow is always left plain. One side of the bow is generally flattened, and there is enough difference between them for each man to know his own.

Animals speared or caught in pit-falls are as follows:—Rhinoceroses, hippopotami, giraffes. Animals shot with arrows: lions, gazelles, wild boars, leopards, foxes, elands, tetels, ostriches, buffaloes, baboons. Crocodiles are killed by a barbed spear, the iron head of which has a line attached to it, and is readily detached from the handle as soon as the beast is speared. Baboons are only attacked by a number of men together; it would be unsafe for a single man to attempt it. No nets, palings, or trenches are used in capturing game. There are no firearms in the country. Clubs are used; a favourite pattern is egg-shaped.

Animals.—The jungles abound in wild animals, the number and variety of which afford a wide field of sport for the hunter, and a choice abundance of food for the whole tribe.

The following animals are hunted, and all except leopards, baboons, and foxes are used as food :—Elephants, buffaloes, gazelles, rhinoceroses, hippopotami, crocodiles, wild boars, leopards, giraffes, elands, baboons, tetels, rabbits, porcupines, ostriches, guineafowls, wild ducks, pigeons, and various other species of beasts and birds which I am unable to identify.

The animals in a state of domestication are cattle, sheep, goats, dogs, and fowls. Fowls are fed with semsem and dhurra. A conical stone house is made for them close by the dwelling-hut, but no porches are provided. The people keep bees. The hives are made of basket-work, and fixed on the branches of a tree. The man who takes them up makes at the same time a sort of whistling noise, which seems intended to be a call to the bees. A hole is left at the bottom of the hive to allow of the bees getting in, and of the honey being subsequently taken out. To accomplish this a basket is pulled up, filled, and let down again, the use of a branch as a pulley being evidently unknown. Sheep and goats are kept in large numbers. Their sheds have wooden walls with thorns fixed on them, as a protection from hyenas, and they are roofed in like the dwelling-huts.

Gazelles and tetels are tamed when caught young, the former being fed on goats' milk and the latter on cows' milk. The tetels are kept for the purpose of milking. Rabbits are tamed, but not very successfully, as when they are full grown they generally manage to escape. Birds are not kept in captivity. The domesticated dogs are all smooth, and do not vary much in size, being about as large as our fox terriers. In colour they are either white, black, or brown, or black or white. They are intelligent, and show much affection and fidelity to their own masters. They are liable to hydrophobia, and when seized with it are at once killed. There is also a kind of wild dog, of smooth skin, reddish-brown colour, and a fox-like head and long ears. Dogs are the only animals which are trained. They prove of great use in hunting gazelles, buffaloes, and some small animals.

Horses are unknown, and only very recently have a few asses

been introduced by the Arabs. There are no mule animals. Castration is not practised.

Two kinds of migratory insects visit the country. When the dhurra is ripe, green flies about 1½ inches long arrive in swarms; many are caught and eaten, and the remainder take their departure in the opposite direction from which they came. Swarms of locusts follow them. These are also eaten.

When they leave, a species of small red bird takes possession of the fields. They build their nests in the trees near the fields of the dhurra, and remain until the corn is too dry for them to eat.

Once a year the white ants swarm; when this is expected a fire is lighted near the ant hill, the ants are knocked down, gathered, preserved in jars, and much relished as food. Fleas and mosquitoes are very abundant.

There is no worship of animals, and the people do not believe in the interchange of souls between men and animals. There exists, however, some sort of superstition concerning one small bird called "dadir." It is caught when young, and small rings are fastened to its legs, after which it is set free, and no one is permitted to harm it in any way. They think that it is unlucky to hurt it; and should a man by accident break its leg, they expect one of his cows to get its leg broken. The feathers of another highly-valued red bird are used to try by ordeal persons accused of falsehood. It is considered to be a bad omen if a gazelle crosses a man's path; and if it should occur, the man usually turns back and gives up his project, whatever it may be. The lizard is known, and no one is allowed to kill it.

Various curious legends prevail with regard to animals. I will mention one as a specimen.

A monster lion is said to have shaken the earth by his roars. The shock was so great that all the people fell to the ground, and the lion proceeded to eat them. One man, however, entreated the Being, who had created both man and beast, to make the lion a little smaller, as he was too great and powerful for men; his request was granted, and the lion forthwith was reduced in size to his present dimensions.

Among numerous fables, the following may be given:—

On a certain occasion the animals all meet together to dance and

enjoy themselves. Soon, however, they found that they were encircled by men, who set fire to the grass on all sides. The rabbit was most officious in proposing plans of escape. One of his suggestions was that the weasel (?) should make a hole in the ground, into which they might all flee for refuge. When the danger came quite near, he forgot every one else in his endeavours to save himself, but without avail, for they were all burnt up except the weasel (?), and a small bird who had been on the watch, and who, as soon as he saw the danger, warned his friends, and then flew away. The rabbit came to his end as follows:—The weasel (?) had taken his advice and dug a hole in the ground, into which he entered, but the rabbit bit off his tail and pulled him out, getting into the hole himself. In revenge, the weasel told the men where the rabbit was, and as they looked for him the weasel managed to make good his own escape.

Hunting.—The hunting season is a very important time in the Madi country, for it immediately follows a period of agricultural labour, and finds the people ready for the enjoyment of a holiday, and of a sport which they keenly appreciate. When the corn is all dried and stowed away in the granaries, the hunting begins, and continues for several months—that is, until the rain commences again. Very large hunting parties are formed, people from numerous villages assembling together, and being sometimes joined by parties from other friendly tribes.

The following is the way in which the notice of a hunt is given:—A man is sent round to all the villages, and as he passes by each hut he strikes with a peculiar stick one of the stones by the door of the hut. This signal is followed by a formal declaration that a hunt is arranged for a given day, and that all who wish to take part are to meet at a given place. When the time has arrived, and the hunters assembled, they divide into companies, and encircle a tract of country often several miles in extent. One company takes up its position on the side from which the wind blows, and sets fire to the long grass; as it is burnt down, the animals rush towards the other companies, who stand in long double rows, shooting their prey as they pass by. If a buffalo happens to be amongst the fugitives, he usually proves an awkward customer, as instead of running straight forward he will rush into the ranks of his foes, and cause

no little commotion, often killing or wounding several of the huntsmen. When an animal is killed, it is the prize of the man who first shoots it, though its death is probably accomplished by others.

The right of possession does not appear to be decided by distinguishing arrow marks, but great care is taken to identify the shooter, and quarrels often arise about it, and are frequently only settled by a fight. It is virtually a case of much ado about nothing, for this right, which is so jealously guarded, concerns only the tail or the horns of the animal, which are kept as a trophy. Any one who has taken part in a hunt has a perfect right to his share in the booty, which is shared alike by all, each man getting an almost equal part of the spoil. Even should one party be more successful than another, the unlucky hunters get the same share as those who have been successful. Should an animal be first shot with a borrowed bow and arrow, the lender gets the trophy; but such transactions only take place between brothers or very intimate friends. Successful hunters are long kept in remembrance, and their exploits are handed down from father to son.

The Madis do not appear to have any special ceremonies or dances connected with their hunting expeditions, but in subsequent dances, those who have been distinguished in hunting, or women who have been very active in giving water to the men and won special renown, are celebrated in song. No great feast takes place after a hunt, but friends are sometimes invited in small parties to eat buffalo, &c.

Before going to the hunt the men paint their faces in stripes of different colours, and put iron rings on their necks, arms, and (sometimes) ankles, and the white tail of some animal round their necks. They carry their arrows in a goat-skin bag, hung over the shoulder or by a string which passes round the neck. In the left hand they hold the bow and two or three arrows; in the right hand they carry the spear. They start very early, so as to reach the hunting ground soon after sunrise, and they hunt all day. The women start later, carrying water on their heads in earthen jars, in the neck of which bunches of leaves are placed to keep the water cool. A small gourd floats on the top of the water to keep it from spilling, and serves as a drinking-horn.

These large hunting parties are only undertaken in the hunting

season, but individuals hunt at other times. Young people and children hunt rabbits, gazelles, &c., not far from home. Women catch guineafowl by driving them about, as they soon get tired and cannot fly far. Sometimes large companies of boys undertake a hunt for the old women. On their return they all walk together in regular order to the huts where the old women live, laden with the spoil, and for this good work they are always invited to dinner. Should the old women have too much meat brought to them, they make presents to their friends.

All the wild uninhabited land surrounding a tribe belongs to the tribe as a whole, and may be hunted in by anyone. Individuals or parties may also hunt in the country which belongs to a neighbouring tribe, if that tribe is friendly. Should a man go alone to hunt in an enemy's country, he will not be interfered with, if he behaves well; but if he be insolent, the people will fight with him.

The chiefs do not often take part in the hunt; possibly the people do not like them to be needlessly exposed; and there is a tradition of a great chief having been killed in a hunting fray, and his body having been lost.

Gazelles are hunted as follows:—Some of the dogs run in front of the animal to distract its attention, whilst two or three creep quietly up from behind, and seize it. The dogs are kept by individuals, and not in large packs.

All large animals are cut up when killed, and not carried away whole. There is much waste, as what cannot be easily taken away is left. Small game is carried home on the head, or slung on a pole and carried by two men.

The Madis are very skilful with bow and arrow, and can hit birds on the wing. No tribute is paid in game. Water only is drunk while hunting. The meat is dried over a fire to preserve it.

The people are not influenced to migrate by the habits of the animals they hunt; good land is their great desire.

Traps.—The various modes employed for entrapping animals are of interest.

Hippopotami and rhinoceros are caught in pits. Deep holes are dug in the ground, into the bottom of which wooden stakes are driven with spikes projecting from the upper end, and then the holes are covered over with sticks and grass, strong enough to bear a man's

weight, but unable to sustain large animals, which, falling in are often killed by the spikes, or at least badly wounded.

Buffaloes are caught by means of a skin rope attached to a pole which is stuck into the ground; at the end of the rope there is a noose, which is arranged round a small hole dug in the ground; the rest of the rope is hidden by twigs and leaves. The buffalo puts his foot into the hole, and in getting it out the noose is drawn tight, and the animal has to drag the heavy pole. He is thus easily tracked and speared.

To trap guineafowl, a string is made of hair from a cow's tail, a noose is placed among the small branches of a low plant in their run, into this they run their heads and are held fast.

Another trap is made of a long basket with a narrow opening at one end. It is placed on the ground in one of the narrow paths running through the high grass; small animals find their way into it, but cannot get out again, as the twigs of which the basket is made are so arranged inside that they fly back from the sides and prevent the animal retreating.

Birds are caught in the following ways:—

1. A noose is attached to a bent bough, and so arranged as to spring back and snare any bird that touches it.

2. One end of a flat stone is placed on the ground, and the other supported by a stick to which is tied a piece of string. The birds being attracted to food placed underneath the stone, pull the string, and the stone falls on them.

3. A number of sticks are driven into the ground, and nooses fastened to them; dhurra is then scattered about, and as the birds scratch the ground they get their legs caught.

String traps are arranged at the doors of the fowl huts to catch the wild cats when they try to steal the poultry.

At night boys are very fond of catching rats by firelight; they lie flat on the floor, very still, holding a round pan with dhurra in it, the rats come to eat, and as soon as near enough an inverted jar is quickly put over them.

Fishing.—The Madis adopt various methods of fishing.

Sometimes they dive into the water and while swimming underneath stick the fish with an iron hook; a line is fastened to this, the one end of which is wound round the fisher's hand, with which

he also holds the wooden handle. The hook looses from the handle and remains in the fish, the man then swims to land and hauls it in.

Sometimes they fish at night by firelight, shooting the fish with iron-headed arrows. Nets are also used. They are drawn across a river and held at both ends. Men go up stream, and then swim down with a splashing stroke driving the fish to the net. In this way large numbers are caught, and a general distribution of the spoil takes place.

These are the methods employed in catching very large fish. A smaller kind of fish is caught by the women in shallow water. They use a poisonous fruit, about the size of a gooseberry. This fruit they grind into a coarse powder, and carry to the water in baskets. They then scatter it on the surface, and the fish eat it, and soon die. They are afterwards collected in baskets, and as the poison is not injurious to men, they are good for food. Children also fish by shooting with bow and arrow, and swimming after the fish they hit; many lives are lost through boys venturing into rapid rivers.

Sometimes in small rivers, instead of a net, a wickerwork barrier is constructed across the stream; another movable one is then introduced up stream, and gradually carried down until a short distance from the first barrier; the fish thus brought together are then caught by hand, and thrown on to the bank.

A fish trap is also made of wooden latticework, several feet across at one end and narrow at the other; this is placed beneath waterfalls or below rapids. Sometimes nets like our landing nets are held under waterfalls, to catch the fish as they come down. Wooden dams are also erected across rivers. Poles are fixed in the ground and cross beams fastened to them, holes being left of such a size that the fish in trying to get through stick fast and are collected each morning. These dams are left until the river gets swollen by the rains, and washes them away.

Fish are cured by being dried by the fire or in the sun, and keep good for considerable time.

Manufactures—Woodwork.—Numerous articles are manufactured from wood. Ladles, stools, handles for agricultural implements, bows, arrows, and walking-sticks. Nails are not used, bu the articles are either cut out of blocks of wood, or tied together with string, leather thongs, or iron wire. The instruments em-

ployed are—knife, axe, and a kind of plane. Fire is also used to hollow out wood and to harden it.

Smelting.—A hut or shed is set apart for carrying on smelting operations, several men working in the same hut. A number of fires are kept going, and the bellows are used as follows:—A large earthenware bowl with a hole at the side near the bottom is placed near the fire, and a clay pipe is constructed from this hole to the fire. The top of the bowl is covered with a soft skin, in the middle of which a hollow stick is fastened. This stick being moved up and down, and the top being closed by a finger when moving down, causes the draught. The anvils and hammers used are of iron, the hammer being flat in shape. They are thus a little in advance of the surrounding tribes, who only use stone. Some few stone anvils and hammers are, however, still in use in the Madi tribe. Very good knives, hoes, and bracelets are constructed, as well as arrow-heads.

The smelting furnaces are conical in form, and about 5 feet high, layers of iron ore and charcoal being placed alternately. Six pairs of bellows are often used, each man working two, one with each hand. There is not very much beer drinking during the smelting, but a good deal of singing, the men working in time to the song. Relays of men work at this tedious operation.

Basket Work.—The manufacture of baskets is carried on largely. Various shapes and sizes are constructed of open wickerwork; they are made by men much after our own manner.

Baskets of dhurra stalks are woven by women in the following way:—The pulp is removed, the stalks opened out flat and cut into the requisite lengths. The bottom of the basket is first made, and the sides worked up from it, being woven very close. Some kinds of baskets are so closely made that they will hold milk, and small ones are made to serve as cups on a journey, as they are lighter than earthenware, and less fragile than gourds. The shapes vary, being round, square, or otherwise, and of different colours, according to the kind of dhurra stalk used. Sometimes the various colours are blended. Women also make baskets of young doleb palm leaves. Pots are covered by a loose wickerwork for carrying. Spring baskets are made by men. They are chiefly used for ornamental purposes, and not of much practical use.

Pottery.—The manufacture of pottery is carried on by the women. A grey clay having been freed from stones is mixed with water to the consistency of dough; much care is taken that there should be no lumps in it, and that it should not be too wet or too dry. This dough is left in a hut for a day, being placed on and covered by leaves. The women then commence to make the jars, forming the bottom first on a wooden tray, working the sides up with their hands and moulding it into shape. No wheel is used. The vessels made vary very much in size and shape. Some are round and open like our basins, some have narrow necks widening out again at the top. When formed they are ornamented by lines made horizontally and at right angles below the top rim, which is often made to curve over. This marking is done with a sharp bit of stone such as is used for cupping, or with a sharp pointed stick. The jars are then painted black, or black with a red neck. They are left in a hut for a day or two to dry, then put in the sun for a day or two more, and lastly they are fired. Quite a trade is carried on by the makers of pottery, who keep a store of their goods for sale. Some very large sized jars are made for holding semsem; these are made by men, and in forming them a grass mould is used.

Painting.—The Madis decorate their bodies with paint for dances, washing it off again when the festivities are over. Red, blue, white, and black paints are used. The red is oxide of iron, the black is made from charcoal. The paint is applied with the finger in stripes about half an inch broad on the face, arms, shoulders, and chest. Women paint their faces, chest, and upper part of their arms, and some confine the paint to one part of the body only. The designs vary with taste. No application is made to the eyes. They do not stain their nails.

String.—String is made from the fibrous bark of five or six different trees. This substance is first dried in the sun for a day or two, then wetted, and buried for two or three weeks, at the end of which time it is taken out and heaped up under a tree. Here the men work, beating the fibrous pulp with a piece of wood on the smooth trunk of a tree which lies on the ground. They then work the fibres into string by rubbing them into a twist with their hands on their thighs.

To make cord, they fasten two pieces of string to their toes, and

twist them together with their hands, repeating the process until the cord is of the required thickness and length. In making rope a cord is tied between two trees, and others wound round it in a spiral manner.

String is made of various other substances—of the hairs from the cow's tail, of animal skins cut into stripes and twisted (these are very strong, and are used for trapping buffaloes); also from the tendons of cattle and wild animals; this kind is made very fine, two men being needed to work it. It is used for bow strings. String is also made from doleb palm leaves. Fishing nets are made with fibre strings, which is tied into knots by the hand, forming diamond-shaped meshes like our own netting.

No dye is used in making string, but it is sometimes of a red colour, because made with red fibres. No wax is used in this manufacture, but the string is sometimes rubbed with grease. A lump of fat is taken in the hand, and the string drawn rapidly through it. This is also done to the bow strings and nets, but not to the large ropes. As a rule, men make the ropes, and nets, and bow strings; but women make fine twine, and small nets for holding gourds, and for forming bags on which to hang up fruit, &c., to dry in the sun, or from the rafters of the huts.

Money.—A regular system of exchange is carried on in arrows, beads, bead necklaces, teeth necklaces, brass rings for the neck and arm, and bundles of small pieces of iron in flat, round, or oval discs. All these different articles are given in exchange for cattle, corn, salt, arrows, &c.

The nearest approach to money, in one sense, is seen in the flat round pieces of iron, which are of different sizes from $\frac{1}{2}$ to 2 feet in diameter, and $\frac{2}{3}$ inch thick. They are much employed in exchange.

This is the form in which they are kept and used as money, but they are intended to be divided into two, heated and made into hoes. They are also fashioned into other implements, such as knives, arrow heads, &c., and into little bells to hang round the waist for ornament, or round wandering cows' necks.

Ready-made hoes are not often used in barter; iron as above mentioned is preferred, and is taken to a blacksmith to finish according to the owner's requirements.

Any tools may be obtained ready made from a smith, and may be used in barter when new.

Compensation for killing a woman or for any serious crime must be paid in cattle. No cowries are used as coin in this district. No drawing or writing is known, but certain marks are used to distinguish between arrows, pots, and the like.

Measures.—A year is made up of twelve months or divisions, but the number of days in each division is said to vary—I could not make out how or why.

A day is from sunrise to sunset. The year begins about the first month of harvest, when the grain is quite dry. Distance is reckoned by time.

If you ask the distance to a place not very far away, they will often point to the sky and say—"When the sun is at that spot you may be there."

No measure of weight, quantity, or length is used.

The number of cows given to a son, or the number of things lent or borrowed, is remembered by means of small lengths of grass, bundles of which are kept in a basket on the wall of the hut. Dried beans are sometimes used for the purpose.

The Madis count by tens; hundreds are known, but not thousands. Sticks are sometimes notched to remember numbers.

Astronomy.—The twilight in this district is very short. The Madis divide the day into three parts—morning from about 5.30 to 10 A.M.; mid-day 10 to 3 P.M.; and afternoon from 3 to 6.30 P.M. So that, roughly speaking, sunrise and sunset begin and end the day. The names for sunrise and sunset are kadro-ersa, kadro-lobo. There are names too for several of the stars (calu). The Pleiades, Minge Minge. The larger star by which they tell the time, Toru. The milky way, Guguree (road).

Their study of the stars does not seem to go further than giving names to some of them. The winds are called Bluku. East, Duwerie; West, Huwerie. Night, Endo; Morning, Demindo.

Short Vocabulary of Madi Words.

Antelope	Kulă.	Mouth	Haw.
Arm	Kallah.	Mouse	Lusiē.
Arrow	Etu.	Mountain	Doku.
Bedstead	Surah.	Morning	Demindo.
Beads	Biallah.	Night	Endo.
Bow	Keiuyah.	Nose	Kano.
Boy	Uiskorah.	Ox	Dangmo.
Brother	Undŭ.	Pipe	Tuku-taba
Brook	Ranga.	Rain	Mirē.
Buffalo	Kobi.	River	Rodi.
Cat (wild)	Yow.	Rope	Kordi.
Child	Wistissi.	Serpent	Wiri.
Chin	Sisi.	Sister	Emi.
Cow	Isah.	Sun	Kadroa.
Chief	Wisyerra.	Star	Calu.
Crocodile	Tamorah.	Sleep	Kemelli
Dog	Wīhi.	Tongue	Ndenda
Drum (large)	Dattei.	Water	Weni.
„ (small)	Kurai.	Woman	Mbara.
Ear	Mbilli.	Bad	Emeddi.
Earth	Kang-u.	Big	Kiedra.
Elephant	Kidi.	Black	Korndu.
Eye	Komang.	Blue	Muri.
Father	Dadă.	Good	Emettakin
Face	Komomah.	Green	Yowi.
Fire	Wado.	Heavy	E-ebtu.
Fish	Censa.	Little	Tissi.
Fish-hook	Mongo.	No	Lah.
Finger	Denjerida.	Red	Ei-hi.
Flute	Traülei.	White	Einyi.
Foot	Mīndima.	Yes	Wah.
Forest	Wevu.	1	Korlo.
Fowls	Yaru.	2	Irio.
Giraffe	Kerri.	3	Utah.
Girl	Uiyo.	4	Suwor.
Goat	Wanya.	5	Mwi.
Grass	Lomah.	6	Dakka.
Head	Do.	7	Demrio.
Harp	Taumu.	8	Dumta.
Hair	Iavu.	9	Dumsor.
House	Loko.	10	Dumte.
Iron	Kor-hi.	11	Dumte Korlo.
King	Yerra.	12	„ Irio.
Knife	Evu.	13	„ Utah.
Lake	Ulu.	14	„ Suwar.
Leg	Ndi.	15	„ Mwi.
Lion	Ubiu.	16	„ Dakka.
Man	Kurah.	17	„ Demrio.
Moon	Niahoa.	20	Bute-Irio.
Mother	Ma.	30	Bute-Otah.

I consider that these notes would be far from complete were I to omit some mention of the Madi language. I have, therefore, given above an extract from the vocabulary I collected The language is

rich and melodious, and apparently lends itself well to oratory and song. It belongs to the Negro group of languages, for the Madis are pure negroes.

Note.—I had at first intended to illustrate this paper with drawings from objects in my collection, which are interesting as being the only ones that have yet found their way into Europe. Finding, however, that somewhat similar articles may be found depicted in *Geschichte der Waffen*, Band iii., Berlin und Leipzig, 1877, and in Schweinfurth's *Artes Africanæ*, Sampson Low, 1875, this has been deemed unnecessary.

4. On the *Crinoidea* of the North Atlantic between Gibraltar and the Faeroe Islands. By P. Herbert Carpenter, D.Sc. (Camb.), Assistant Master at Eton College. With some Notes on the *Myzostomida*, by Prof. L. von Graff, Ph.D. Communicated by Mr John Murray.

Introduction.

This communication falls conveniently into two sections—I. dealing with the specimens obtained by H.M.SS. "Lightning" and "Porcupine," during what may be called the pre-Challenger period of deep-sea exploration; II. concerning those dredged by the "Knight Errant" and "Triton" during the surveys of the Wyville Thomson ridge, which were conducted in the years 1880–82.

All the species will be properly described and illustrated in the "Challenger" Reports; but many reasons seem to render it desirable that some of them, and more especially the *Comatulæ*, should be briefly noticed before the larger report can be published.

My friend Professor L. von Graff has kindly sent me a short account of the *Myzostomida*, from which it will appear that four species of these parasites have been added to the two already known in the British seas.

I. *The Crinoids obtained by H.M.SS. "Lightning" and "Porcupine,"* 1868–70.

The detailed zoological results of the preliminary dredging expeditions of the "Lightning" and the "Porcupine," in the years 1868–70, have been so completely cast into the shade by the mag-

nificent collections of the "Challenger," that little is known about many of the deep-sea animals obtained by these expeditions beyond the first references to them in the reports of Sir Wyville Thomson, Dr Carpenter, and Dr Gwyn Jeffreys, in the *Proceedings of the Royal Society.*

The Annelids, Corals, Echinids, and Mollusca soon found their way into able hands, and have been fully described in the publications of various learned societies. But as regards most of the other groups no detailed results have ever been published. This want of systematic information about our earlier expeditions is not to be wondered at, when it is remembered that the "Challenger" sailed but little more than two years after the return of the "Porcupine" from the Mediterranean, and that Sir Wyville Thomson, in whose hands the collections mostly remained, was in bad health, with his time much occupied by his professional duties and by the preparations for his four years' absence. When he returned the "Porcupine" collections were entirely dwarfed by those of the "Challenger;" and it is only now that they have been examined by Mr Murray that specimens dredged nearly fifteen years ago are coming into the hands of specialists, who are working them up together with the "Challenger" material, and with that of the "Knight Errant" (1880) and "Triton" (1882).

Nearly the same thing has taken place on the other side of the Atlantic, little being yet known about many of the types obtained by the U.S. ships "Corwin," "Bibb," and "Hassler" (1868, 1869, 1872); and they are now being described by those specialists, in whose hands have been placed the larger collections of the "Blake" (1877–80), second only in importance to those of the "Challenger."

Before sailing in the "Challenger," Sir Wyville Thomson read before the Society a paper* entitled "On the Crinoids of the 'Porcupine' Deep-Sea Dredging Expedition." It was, however, by no means complete, as regards either the list of species obtained or their geographical distribution; and in the following pages I propose to partially make good this deficiency. When our knowledge of the Crinoids fifteen years ago is taken into consideration, the material obtained by the "Porcupine" must be regarded as com-

* *Proc. Roy. Soc. Edin.*, vol. vii. pp. 764–773. A large portion of this paper was also printed in *The Depths of the Sea*, pp. 434–454.

paratively rich. For it includes four stalked Crinoids, three of which were new to European seas and also new to science, while one represents a new generic type altogether; and among the seven *Comatula* species were three or possibly four new forms, one representing a genus which, up till very lately, has scarcely been known to occur outside the limits of the tropics. Sir Wyville Thomson's list embraces only seven species of Crinoids altogether; whereas eleven different types were really obtained, seven being *Comatulæ*, and four stalked Crinoids, the latter including three additions to the four species then known.

These facts seem to me of sufficient interest to merit being treated separately, so that they may not be lost sight of in the general account of the Crinoids which will appear in the "Challenger" Report.

Family PENTACRINIDÆ.

Genus *Pentacrinus*, Miller.

Cainocrinus, Forbes.
Picteticrinus, de Loriol.

1. *Pentacrinus wyville-thomsoni*, Jeffreys.

H.M.S. "Porcupine," 1870. Station 17. Lat. 39° 42′ N., long. 9° 43′ W. 1095 fathoms. Temp. 39°·7 F. Ooze. "About twenty specimens."

Remarks.—This fine species was worthily dedicated to Sir Wyville Thomson, in the Report of Drs Carpenter and Gwyn Jeffreys; but no further description of it was published until the appearance in 1872 of *The Depths of the Sea.* This contains a good figure, with a description by Sir Wyville, which is identical with that given in his paper on the "Porcupine" Crinoids. A series of five beautifully executed plates, illustrating the anatomical characters of the skeleton, which were drawn by Mr Hollick for Dr Carpenter, will appear in the "Challenger" Report.

P. wyville-thomsoni has a closed ring of basals, and would therefore belong to Forbes' genus *Cainocrinus*, which has recently been revived by de Loriol.* I have elsewhere given my reasons for regarding *Cainocrinus* as indistinguishable from *Pentacrinus*.†

* *Monographie des Crinoïdes fossiles de la Suisse*, p. 111.

† *Journ. Linn. Soc. Zool.*, vol. xv. p. 210; and *Bull. Mus. Comp. Zool.*, vol. x. No. 4, p. 168.

Family Bourgueticrinidæ, de Loriol.

Genus *Rhizocrinus*, M. Sars, 1868.

Bourgueticrinus, Pourt., 1868.
Democrinus, Perrier, 1883.

2. *Rhizocrinus lofotensis*, M. Sars, 1868.

Bourgueticrinus hotessieri, Pourt. 1868.
Rhizocrinus lofotensis, Wyv. Thomson, 1872 (pars).

H.M.S. "Lightning," 1868. Station 12. Lat. 59° 36′ N., long. 7° 20′ W. 530 fathoms. Temp. 47°·3 F. Globigerina ooze. Three small specimens without arms.

Station 16. Lat. 61° 2′ N ; long. 12° 4′ W. 650 fathoms Globigerina ooze. Two small specimens without arms.

"Once or twice we found a fragment of the stem of *Rhizocrinus* in the cold area." *

Remarks.—So far as my information goes, this widely distributed species was never dredged by the "Porcupine," not even on the the "*Holtenia*-ground" in 1869. But according to Sir Wyville,† "several occurred attached to the beards of the *Holteniæ* off the Butt of the Lews." This would be at Stations 47 and 90, both of them close to No. xii. of the "Lightning" cruise, which was the original *Holtenia*-ground, and was described by Sir Wyville as being in the Faeroe channel. There is, however, no mention of *Rhizocrinus* in the accounts of the dredgings at these stations, either in *The Depths of the Sea*, or in the Royal Society Report; and I suspect therefore that Sir Wyville was speaking from memory only, and confounded the dredgings of the two years. At any rate, if the "Porcupine" did obtain specimens on the *Holtenia*-ground in 1869, they have since disappeared.

Sir Wyville mentioned individuals of considerable size as having been dredged by the "Porcupine" in 862 fathoms off Cape Clear. They really belong, however, to the species which three years later was met with off Barbadoes by the "Hassler," and was subsequently described by Mr Pourtalès under the following name :—

* *The Depths of the Sea*, p. 124. † *Ibid.*, p. 450.

3. *Rhizocrinus rawsoni*, Pourt., 1872.

Rhizocrinus lofotensis, Wyv. Thomson, 1872 (pars).
Rhizocrinus rawsoni, P. H. Carpenter, 1882.
Democrinus Parfaiti, Perrier, 1883.

H.M.S. "Porcupine," 1869. Station 42. Lat. 49° 12′ N., long. 12° 52′ W. 862 fathoms. Temp. 39°·7 F. Ooze with sand and shells. Two armless specimens.

Station 43. Lat. 50° 1′ N., long. 12° 26′ W. 1207 fathoms. Temp. 37°·7 F. Globigerina ooze. Two young specimens, one without arms.

Remarks.—These four specimens, as already indicated, were really the first discovered examples of *R. rawsoni;* but they differ from *R. lofotensis* far less than the Caribbean individuals do.* Those from Station 42 were noticed by Sir Wyville at the time they were obtained, and described as unusually large examples of *R. lofotensis.* But I am not aware that he ever made a closer examination of them. After reading Pourtalès' description of the Caribbean *R. rawsoni*, I came to the conclusion that the "Porcupine" specimens should really be referred to this type; and this view was confirmed when the originals of Pourtalès' description were sent to me last year (1882), as I have pointed out in my "Blake" report.

The two young individuals from Station 43 seem to have been altogether overlooked; for they are not mentioned either in the Royal Society's Report, *The Depths of the Sea*, or the paper on "Porcupine" Crinoids. They did not come into my hands until August last, having been discovered by Mr Murray among Sir Wyville's collections at the University. They are the youngest specimens of this type which I have seen. Each has 28 joints in the stem, from the calyx to the root; but its length, which is only 20 mm. in the smaller, is 24·5 mm. in the larger individual. The majority of the joints are cylindrical and elongated, only a very few at the base of the stem showing the characteristic dice-box shape with expanded ends. The length of the calyx is almost the same in both specimens, 1·8 mm.; though its diameter across the

* "The Stalked Crinoids of the Caribbean Sea," *Bull. Mus. Comp. Zool.*, vol. x. No. 4, pp. 174, 175.

radials is greater in that which has the longer stem. It is mainly composed of the basals, which are 1·2 mm. in height, and form a nearly cylindrical tube, at the top of which are the short radials, having a more decided upward and outward slope. This causes the calyx to appear slightly constricted at the level of the basiradial suture, a feature which is very marked in some varieties of the adult form.

As compared with equal sized specimens of *R. lofotensis*, these young individuals of *R. rawsoni* are distinguished by the relatively great height of the calyx in proportion to its width, the length of the basals, and the expansion of the calyx at the basiradial suture. The basals of *R. lofotensis* (uppermost stem-joint, Sars.) have a smaller share in the formation of the cup, and it expands uniformly upwards from the stem to the upper margin of the radials.

It is noteworthy that even these two young individuals from the same locality present differences in the shape of the calyx such as are more distinct in adult specimens from different localities in the East and West Atlantic. Perrier's genus *Democrinus* * is founded upon a variety of unusual size, with a great disproportion in the heights of basals and radials, and a somewhat strongly marked circular furrow at the level of the highest points of the basals, so that it crosses the middle of the radials.

Genus *Bathycrinus*, Wy. Th., 1872.

Ilycrinus, Danielssen & Koren, 1877.

4. *Bathycrinus gracilis*, Wy. Th., 1872.

H.M.S "Porcupine," 1869. Station 37. Lat. 47° 38′ N., long. 12° 8′ W. 2435 fathoms. Temp. 36°·5 F. Globigerina ooze.

One nearly complete specimen, and one stem with the basal ring attached, but wanting the rest of the calyx.

Remarks.—A figure of this species was given by Sir Wyville Thomson on page 453 of *The Depths of the Sea*, together with the same description which he published in his paper on the

* Sur un nouveau Crinoïde fixé, le *Democrinus Parfaiti*, provenant des dragages du "Travailleur," *Comptes Rendus*, Tome xcvi. No. 7, pp. 450, 451. See also "Note on *Democrinus Parfaiti*," *Ann. & Mag. Nat. Hist.*, May 1883, p. 335. I am indebted to Professor Perrier's kindness for a drawing of this interesting type.

"Porcupine" Crinoids. This, however, is not quite accurate, for there is no mention of any calyx-plates below the radials, the lower portion of the head being said to consist "of a gradually expanding funnel-shaped piece, which seems to be composed of coalesced upper stem-joints." Subsequently, however, Sir Wyville found that in *B. aldrichianus*, from the Southern Sea, there is "a series of basals which are soldered together into a small ring, scarcely to be distinguished from the upper stem-joint."* The existence of basals in *Ilycrinus* (*Bathycrinus*) *carpenteri* was also recognised by Danielssen & Koren,† who were fortunately able to see the interbasal sutures in young individuals, though they entirely disappear in the adult; and there is a similar basal ring in *B. gracilis*, intervening between the radials and the numerous thin joints at the top of the stem.

The two outer radials and the two lowest brachials of *B. gracilis*, and also of *B. aldrichianus*, were described by Sir Wyville as respectively united by syzygy, while Danielssen and Koren made the same statement respecting *B. carpenteri.* In all these cases, however, the supposed syzygy is really a modification of the ordinary bifascial articulation permitting lateral movement only, which is so common in the *Comatulæ*, and is also characteristic of four species of *Pentacrinus;* for a third and smaller bundle of fibres is inserted into a deep pit at the lower or dorsal end of the vertical articular ridge on each joint-face. Externally, this form of articulation looks very much like a syzygy, as the joints are brought into closer connection than when they are united by a pair of muscular bundles. But a glance at their terminal faces is sufficient to show that the plainness of *Pentacrinus* or *Rhizocrinus*, or the striation of the *Comatula*-syzygies is altogether absent, and that they are marked by distinct ridges and fossæ.

According to Sir Wyville's description, there are none of these so-called "syzygies" in the arms of *B. gracilis* beyond that between the first two joints; while in *B. aldrichianus* there is a syzygy between the fourth and fifth brachials, and at irregular intervals beyond them; but the "alternate syzygies in the arms, which form

* "Notice of new living Crinoids belonging to the Apiocrinidæ," *Journ. Linn. Soc. Zool.*, vol. xiii. p. 50.

† *Nyt. Mag. for Naturvidskaberne*, Bind. 23, p. 4.

so remarkable a character in *Rhizocrinus*, are absent." I find, however, that in both species the grouping of the arm-joints is exactly the same as was observed in *B. carpenteri* by Danielssen and Koren, if the term "trifascial articulation" be substituted for "syzygy" in their descriptions. In the nine lowest brachials there are alternations of a pair of joints united trifascially, and a single joint with muscular attachments at each end; while beyond the ninth brachial the two forms of articulation alternate with great regularity. The presence of this trifascial articulation, and its peculiar distribution may therefore be considered as characteristic of *Bathycrinus;* and the "alternate syzygies" in the arms, which are supposed to be absent in this genus, are really present in a modified form. Neither do the arms "resemble in character the pinnules of *Rhizocrinus*," or "show no trace of pinnules" in *B. gracilis*. For one or two of them have little stumps on their terminal joints, which give them the appearance of bifurcation, just as at the growing points of the arms of young *Comatulidæ* and *Pentacrinidæ;* and I see no reason to doubt that these stumps are the commencing pinnules.

Family Comatulidæ.

Genus *Antedon*, Frém.

5. *Antedon rosacea*, Linck. sp.

"Frequent in water of moderate depth."* One individual which seems to belong to this species, though certainly representing a rather strongly marked variety, was obtained somewhere in the North Atlantic, but the exact record of its locality has unfortunately been lost.

Among the numbers of *Ant. phalangium* of various ages which were dredged in 1870, at 30 to 120 fathoms, on the Skerki Bank, and at 50 to 120 fathoms, in the Bay of Benzert, on the Tunis coast, were five young specimens certainly not belonging to this type, and probably, therefore, to be referred to the Mediterranean variety of *Ant. rosacea*. It is impossible to state now the exact depth from which they were collected, but it was probably not below 50 fathoms, as *Ant. rosacea* has not yet been found in the

* *Proc. Roy. Soc. Edin.*, vol. vii. p. 765.

Mediterranean at a greater depth than 37 fathoms. I am still in doubt whether some of the very varied forms usually referred to this type should not be distinguished by the name *Ant. milleri*, as was done by Müller, and more especially by Sir Wyville Thomson. But I would postpone giving a decided opinion until I have been able to add considerably to my already large series of specimens from widely-separated localities.

6. *Antedon phalangium*, Müll. sp.

Comatula woodwardii, Barrett.
Comatula celtica, Barrett.
Antedon celticus, Wyv. Th. &c.
Non *Antedon celtica* of von Marenzeller, and Sladen.

H.M.S. "Lightning," 1868. Station 13. Lat. 59° 5′ N., long. 7° 29′ W. 189 fathoms. Warm area.

H.M.S. "Porcupine," 1869. The Minch, 60 to 80 fathoms. Several specimens. Off Loch Scavaig, Skye.

1870. Station 13. Lat. 40° 16′ N., long. 9° 37′ W. 220 fathoms. Temp. 52° F. Several specimens.

Off Cape Sagres, 45 fathoms. Several specimens.

Off Carthagena, 80 fathoms. Several specimens.

Bay of Benzert, 50 to 100 fathoms. Abundant.

Skerki Bank, 30 to 120 fathoms. Abundant.

Remarks.—It has been noted elsewhere * that Barrett's *Ant. celtica* from Skye is really identical with the *Ant. phalangium* of Müller, which was considered until lately as one of the rarities of the Mediterranean, for it inhabits somewhat deeper water than *Ant. rosacea.* Sir Wyville Thomson noted it as occurring "in local patches to 150 fathoms off the north coast of Scotland;" but I have no record of it besides Stat. xiii. of the "Lightning" expedition, and neither the "Knight Errant" nor the "Triton" ever met with it.

The occurrence of this species off the Spanish and Portuguese coasts is of some interest; for it had not previously been recorded between the Mediterranean and the Minch. Curiously enough, it seems (until this year) never to have been obtained in any of the

* "Note on the European *Comatulæ*," *Zool. Anzeiger*, Jahrg. iv. p. 520.

numerous dredgings, both public and private, off the French and British coasts between the parallels of 40° and 57°. One would certainly have expected its appearance during the first cruise of the "Porcupine" in the neighbourhood of the 100-fathom line on the west of Ireland; but no traces of it were met with. It was very abundant off the Tunis coast, both on the Skerki Bank and in the Bay of Benzert, specimens of all ages coming up on the tangles in great numbers, though unfortunately in a very much mutilated condition. These were noticed by Sir Wyville Thomson in the following passage: *—"Many examples of the form known to Continental naturalists under the name of *A. mediterraneus*, Lam. sp., were dredged in the Mediterranean off the coast of Africa. I do not feel satisfied that this is identical with *Antedon rosaceus* of the coast of Britain, though the two specific names are usually regarded as synonyms. There is a great difference between them in habit, a difference which it is difficult to define." It is curious that the extreme length of the dorsal cirri of these individuals did not lead Sir Wyville to identify them with *Ant. phalangium* (*celtica*, Barrett), of which this is one of the special marks, as he himself points out. But I am strongly inclined to believe that he is right in differentiating the common Mediterranean type from the British *Ant. rosacea.* As pointed out above, however, the "Porcupine" only got a very few young specimens of it on the African coast.

It is singular that while no parasitic *Myzostoma* occurred among the numbers of *Ant. phalangium* dredged on the Tunis coast, some of the individuals obtained in the Minch in 1869, and at Station 13 in 1870 (off Mondego) proved to be the hosts of a new species, *M. alatum*, which is briefly described by Professor von Graff further on. A single example of another new species, *M. pulvinar*, was also found attached to the peristome of one of the Minch specimens of *Ant. phalangium*, which does not appear to serve as host to the same species of *Myzostoma* as occur on *Ant. rosacea.*

7. *Antedon dentata*, Say, sp.

Antedon Sarsii, auct.

H.M.S. "Porcupine," 1869. Station 51. Lat. 60° 6′ N. long., 8° 14′ W. 440 fathoms. Temp. 42° F. One specimen.

* *Proc. Roy. Soc. Edin.*, vol. vii. p. 765.

Station 54. Lat. 59° 56′ N., long. 6° 27′ W. 363 fathoms. Temp. 31°·4 F. One specimen.

Station 55. Lat. 60° 4′ N., long. 6° 19′ W. 605 fathoms. Temp. 29°·8 F. Two specimens.

Station 74. Lat. 60° 39′ N., long. 3° 9′ W. 203 fathoms. Temp. 47°·6 F. Three specimens.

1870. Station 17*a*. Lat. 39° 39′ N., long. 9°39′ W. 740 fathoms. Temp. 49°·3 F. One specimen.

Remarks.—This species occurs in profusion at moderate depths off the New England coast, over 10,000 individuals having been obtained by the "Fish Hawk" at a single haul. It is also abundant at moderate depths off New Jersey, near the locality (Great Egg Harbour, N.J.) whence Say's original specimens were obtained; and it agrees so well with his description of *Ant. dentata*, that the identity of the two can hardly be doubted.* The adoption of his specific name thus becomes inevitable, however undesirable this may seem to European naturalists, who have been so long accustomed to associate the type with the name of a deservedly honoured Norwegian zoologist.

Sir Wyville Thomson gave no definite list of stations for this species, though he mentioned the occurrence of more or less complete specimens or fragments in nearly every one of the deep hauls of the dredge from the Faeroe Islands to Gibraltar. So far as I am aware, its southernmost limit in the East Atlantic, and also its lowest bathymetrical range are at present united in Station 17*a* of the "Porcupine," 1870; 740 fathoms. It was obtained at 605 fathoms in the "cold area" in the previous year; but the U.S. Fish Commission have not dredged it below 238 fathoms off the New England coast.

Sir Wyville Thomson stated that one or two small examples of the pentacrinoid were procured in the Faeroe channel. Only one, however, has come into my hands. It is a trifle more advanced than that represented by Sars in figs. 9 and 11 on Tab. V. of his classical *Mémoires*. The arms are longer, with the first pinnule on about the twelfth joint. There is, however, but one cirrus, which seems to be the only one as yet developed, though it is of considerable size, reaching up to the level of the radial axillaries.

* See Verrill, *Am. Journ. Sci.*, vol. xxiii. p. 222.

The stem is attached by a slight calcareous expansion at about its 35th joint to one of the rays of a *Rhabdammina abyssorum;* and it then passes on to form two other spreading attachments, with radicular branches sprouting from them on what appears to be a portion of a tubular hydroid.

8. *Antedon eschrichti*, Müll. sp.

H.M.S. "Porcupine," 1869. Station 57. Lat. 60° 14′ N., long. 6° 17′ W. 632 fathoms. Temp. 30°·5 F.

Sir Wyville Thomson stated that considerable numbers of this species were obtained in many of the cold area hauls; and he noted their small size as compared with more northern specimens. No. 57, however, is the only station of which any record has been preserved; and it is interesting as being by far the greatest depth at which this species has yet been met with. Its usual parasite *Myzostoma gigas*, Lütken, MS., was also obtained at this station.

Two pentacrinoids besides that of *Ant. dentata* were dredged in the cold area; but I do not think that either of them can be the one referred to by Sir Wyville Thomson in the following passage:—"A single example of a pentacrinoid in an early stage was found associated with *Ant. eschrichtii.* It resembled closely the larva of *Ant. sarsii* but the specimen was not sufficiently perfect for a critical examination." Neither of the larvæ which I am about to describe is at all like that of *Ant. dentata*, and I fear, therefore, that the one mentioned by Sir Wyville Thomson has somehow been mislaid.

No. 1. In this larva there is no trace of cirri, the anal plate separates two of the radials, and the arms are just beginning to sprout from the radial axillaries. There are five discoidal joints at the top of the broken stem, which is much more robust than that of the corresponding stage of *Ant. rosacea;* while the head, which exceeds 1 mm. in length, is nearly twice as big as that of the *rosacea* larva. The orals which rest directly on the radials recall those of *Hyocrinus*, having a deep median groove, only more marked than in that type, with the lateral edges folded over somewhat strongly. This interesting larva may perhaps belong to *Ant. phalangium*, but I rather doubt such being the case. For that species is almost the nearest ally of *Ant. rosacea;* and from what I

have seen of the condition of the youngest unattached individuals, I should judge that the larva was not very different from that of *Ant. rosacea.*

I think it much more probable, judging from the robust nature of this larva, that it belongs either to one of the Arctic species, *Ant. eschrichti*, or *Ant. quadrata*, sp. n., or to *Ant. hystrix*, sp. n., which is as yet only known from the cold area. It is very likely only a younger stage of the larva next to be described.

No. 2. The stem, which is broken some 20 mm. from the calyx, forms an attachment to a hydroid tube at about its 30th joint, and is continued downwards half a dozen joints further. There are five discoidal joints below the rudimentary centrodorsal, which bears the sockets of five short cirri. Only one of them remains, however, reaching up to the top of the basals, which make up about half the height of the cup. The second radials and axillaries are well developed, as are also the arms, which are unfortunately broken at about the tenth joint. But even under these circnmstances the head has a length of 4 mm. A slightly bifid plate, having a somewhat worn appearance, stands up in one of the interradii of the disc. It may be one of the orals, or as I am more inclined to think, the anal plate; for I cannot make out anything corresponding to it in the other interradii, which are, however, but imperfectly visible. A striking feature of this very robust larva, and one in which it resembles *Ant. dentata* rather than *Ant. rosacea*, is the large development of the arms before the appearance of the cirri. The radials and brachials are much larger than those of a recently detached individual of *Ant. rosacea.* This is also the case in a "Challenger" pentacrinoid from Ascension, which has a robust appearance like the one under consideration. The latter must certainly belong to one of the three *Antedon* species already mentioned as occurring in the cold area, though further identification is impossible.

9. *Antedon hystrix*, P. H. Carpenter, 1883.

Formula,* $A \,.\, 10 \,.\, \frac{c}{bc}$ ·

Centrodorsal hemispherical, and thickly covered with numerous

* For an explanation of the signs used in these formulæ, see F. J. Bell, *Proc. Zool. Soc.*, 1882, pp. 530–535; and P. H. Carpenter, *ibid.*, pp. 731–747.

long-jointed cirri, which vary considerably in appearance. One of the largest reaches 36 mm., and consists of forty smooth joints, of which all but the basal and terminal ones are longer than broad, the fifth to the tenth being especially so. The cirri attached round the upper edge of the centrodorsal are all of this smooth type, and may be observed in every stage of growth. But those attached nearer the dorsal pole are somewhat different in appearance. They are more slender, and their component joints are relatively shorter than in the other type; while the joints have slightly expanded distal ends, so as to overlap their successors. This is especially marked on the dorsal side, which is produced into a sharp forward projecting spine. I have reason to believe that these characters gradually disappear as the joints increase in age, and that the mature cirri of the two types are not very different in appearance, especially about what might be called the equator of the centrodorsal. But the smooth young cirri all round its edge are totally different from the spiny ones nearer the dorsal pole.

Traces of the first radials may be seen at the angles of the calyx; but there is no constancy about their appearance even in individual specimens. The second radials are short, even at the sides, and are often not visible at all in the middle line of the ray, owing to their being very deeply incised to receive the strong backward projections of the axillaries. These are quadrate in form, with their sides curved, especially the anterior pair; and they are distinctly longer than wide, sometimes almost seeming to overlap the centrodorsal; but much less than half the length is in front of the line joining their lateral angles. The first brachials have long outer sides and very short inner ones, but (like the second radials) are almost invisible in the middle line of the arm, owing to the very strong backward projections of the irregularly triangular second brachials, which nearly reach the axillaries. Both on these joints and on the rudely oblong third brachials, which are much wider than long, the pinnule-socket is placed much nearer the dorsal surface than usual. The next following joints are short and quadrate, with curved proximal and distal edges; and the pinnule is on the shorter side, the longer being marked by a backward projection.

There are syzygies in the 3rd and 8th brachials, and then at intervals of three or four joints throughout the rest of the arm. The

lower brachials are triangular and slightly wider than long; but they slowly become quadrate and finally slightly elongated towards the arm-ends.

The first pair of pinnules (on 2 and 3 br.) are much longer and stouter than the next pair. They reach nearly 15 mm., and consist of some thirty smooth joints, the first six of which are short and nearly square. The second pair have but eighteen or twenty slender joints, and are only about 6 mm. long. The following pinnules increase gradually, both in length and stoutness, reaching 15 mm. in the outer parts of the arms. The two basal joints become slightly flattened and the succeeding ones elongated. They have a somewhat glassy aspect, especially in the later pinnules, while their ends present the usual dead white appearance. The same difference presents itself in the joints of the younger and more spiny cirri round the dorsal pole, and also in the pinnules and cirri of *Ant. dentata.* It recalls the contrast between the hyaline and porcellanous types of Foraminifera, though due to entirely different causes. The ovaries are long and fusiform, extending over the greater part of the length of the lower pinnules; and the disc is naked, or rather closely covered with irregular polygonal plates.

Diameter of centrodorsal 5 mm.; spread about 170 mm.

H.M.S. "Porcupine," 1869. Cold area? Two specimens, bearing seven individuals of *Myzostoma cirriferum*, F. S. Leuckart.

Remarks.—The foregoing description is based upon the characters presented by three examples of the type, two obtained by the "Porcupine" and one by the "Triton." They all agree very closely in their general features, and especially in the curious dimorphism of the cirri, which recalls that already noticed in *Eudiocrinus varians.** The shape of the axillaries and of the second brachials is very striking, the great length of the former being much more marked than in *Ant. eschrichti.* It is the characters of the radials and three lowest brachials which principally distinguish *Ant. hystrix* from *Ant. prolixa*, Sladen.† Both species are remarkable for the small size of the second, as compared with the

* *Journ. Linn. Soc. Zool.*, vol. xvi. pp. 496, 497.

† Duncan and Sladen, *A Memoir on the Echinodermata of the Arctic Sea to the West of Greenland*, p. 77, pl. vi. figs. 7–10.

first pair of pinnules; and this peculiarity distinguishes them from *Ant. phalangium.*

None of the cirri of *Ant. hystrix* reach the size of those borne by the smaller examples of *Ant. prolixa.* Many of these have a short dorsal spine on the distal edge which projects forwards over the base of the next joint, just as in the more centrally placed cirri of *Ant. hystrix.*

Ant. eschrichti is described in the "Porcupine" reports as abundant in the cold area. The only record which I have of its occurrence, however, is Station 57 (1869), 632 fathoms. But whether *Ant. hystrix* occurred here or not, we may assume with tolerable certainty that it is a "cold area" species; for the "Triton" specimen was obtained at a station where the temperature was below 0° C.

10. *Antedon lusitanica*, P. H. Carpenter, 1883.

Formula, $A.10.(2).\frac{a}{c}$.

Centrodorsal hemispherical, roughened at the dorsal pole, and bearing about a dozen slender cirri which reach nearly 30 mm. in length. They have about fifty joints, of which the first three or four are quite short, the next three much longer, and the following ones longer than wide, but gradually diminishing up to the fifteenth or twentieth joint. From this point (or earlier) to the end of the cirrus the joints have a well-marked dorsal spine, which is slightly less distinct in those just preceding the terminal claw. Ten arms, or (rarely) two distichals not united by syzygy. First radials scarcely visible except sometimes at the angles of the calyx. The second short and trapezoidal, with a strong median ridge, which is continued on to the axillaries. These are just pentagonal with slight backward projections into the second radials, and their sides are much flattened. This is still more marked on the outer sides of the first brachials, which are longer than their inner sides. The second brachials project more or less backwards into the first, and the third is a syzygial joint, the next three squarish, and the following ones more elongated with very oblique ends. The second brachials bear moderately long pinnules of about fifteen broad joints. The lowest have very prominent dorsal keels which are

continued, though less marked, on to the later joints. The next following pinnules are altogether smaller, consisting of but a few slender joints.

Disc 5 mm. in diameter, thickly covered with numerous small plates, those at the sides of the ambulacra being rather more regularly arranged than the rest.

Colour, in spirit, brownish-white or greenish-white.

H.M.S. "Porcupine," 1870. Station 17*a*. Lat. 39° 39′ N., long. 9° 39′ W. 740 fathoms. Temp. 49°·3 F.

Ten mutilated specimens.

Remarks.—Nearly all the individuals obtained had the arms broken at the syzygy in the third joint beyond the radial axillaries; and it is therefore quite possible that the epizygal of this joint might sometimes have been a distichal axillary. In one example, at any rate, there are two distichal series, each consisting of two joints, the second of which is axillary. This species, therefore, seems to be dimorphic like *Actinometra pulchella*, and to constitute another exception to the general rule that ten-armed types are sharply distinguished from those in which the primary arms divide. The length and spiny character of its cirri, and the peculiarities of its pinnules, readily distinguish it from all the species of *Antedon* hitherto described. But it has many points of resemblance to some of those dredged by the "Blake" in the Caribbean Sea. It is a type of some interest for two reasons: it is the only European *Comatula* which is in the condition of the so called recent Cystid, *Hyponome sarsii*, *i.e.*, with a plated disc and the ambulacra converted into tunnels by the folding down of the plates at their sides; and it is the only European *Antedon* with more than ten arms.

11. *Actinometra pulchella*, Pourtalès, sp.

Antedon pulchella, Pourtalès, 1878.

Actinometra pulchella, P. H. Carpenter, 1881.

H.M.S. "Porcupine," 1870. Station 31. Lat. 35° 56′ N., long. 7° 6′ W. 477 fathoms. Temp. 50°·5 F. Clay.

One mutilated specimen.

Remarks.—I cannot distinguish this form from the smoother variety of that singularly protean species, *Act. pulchella*, of the

Caribbean Sea. It was dredged by the "Blake" at a very large number of stations; but the depth was nowhere over 300 fathoms, and rarely exceeded 200 fathoms; so that its discovery in the "Porcupine" collection increases both its bathymetrical and its geographical range. Except the two species of *Rhizocrinus*, it is the only Crinoid common to the European and Caribbean seas; while it is the only European species of *Actinometra*. This is an essentially tropical genus, a few species only ranging to the parallels of 35°, such as those at the Cape of Good Hope, Yeddo, and this Gibraltar specimen. The depth too, 477 fathoms, is much greater than that at which the genus usually occurs; so that this "Porcupine" specimen which, like *Rhizocrinus rawsoni*, was obtained in European seas long before its discovery on the other side of the Atlantic, is of interest in every way.

The "Porcupine's" discovery of *Actinometra pulchella* in the East Atlantic has been recently confirmed and extended by the dredgings of the telegraph-ship "Dacia," a few dismembered individuals having been obtained in lat. 34° 57′ N., long. 11° 57′ W., at a depth of 533 fathoms.

All the primary arms divide except one; but the number 20 is kept up by the fact that a palmar axillary is present on one of the secondary arms, a point which I do not remember to have met with in any of the "Blake" specimens. This involves a slight addition to the second of the two formulæ which I have given for this dimorphic type,* so that they become

$$\mathrm{a} \,.\, 10 \,.\, \frac{a}{b}\,; \text{ and } \mathrm{a} \,.\, 2 \,.\, (2) \,.\, \frac{\mathrm{b}}{2}\,,\ \frac{a}{b}\,.$$

In the following list of stations at which Crinoids were dredged by the "Lightning" and "Porcupine," the forms which are now noticed for the first time are distinguished by an *.

Station List of Crinoids and Myzostomida, 1868–70.

H.M.S. "Lightning." 1868.

Station 12. Lat. 59° 36′ N., long. 7° 20′ W. 530 fathoms. Temp. 47°·3 F. Globigerina ooze.

Rhizocrinus lofotensis.

* *Proc. Zool. Soc.*, 1882, p. 745.

Station 13. Lat. 59° 5′ N., long. 7° 27′ W. 189 fathoms. Temp. 49°·3 F.

Antedon phalangium.

Station 16. Lat. 61° 2′ N., long. 12° 4′ W. 650 fathoms. Globigerina ooze.

Rhizocrinus lofotensis.

H.M.S. "Porcupine." 1869.

Station 37. Lat. 47° 38′ N., long. 12° 8′ W. 2435 fathoms. Temp. 36°·5 F. Globigerina ooze.

Bathycrinus gracilis.

Station 42. Lat. 49° 12′ N., long. 12° 52′ W. 862 fathoms. Temp. 39°·7′ F. Ooze, with sand and shells.

* *Rhizocrinus rawsoni.*

Station 43. Lat. 50° 1′ N., long. 12° 26′ W. 1207 fathoms. Temp. 37°·7 F. Globigerina ooze.

* *Rhizocrinus rawsoni.*

The Minch, 60 to 80 fathoms; and off Loch Scavaig, Skye.

{ *Antedon phalangium.*
Myzostoma alatum.
M. pulvinar.

Station 51. Lat. 60° 6′ N., long. 8° 14′ W. 440 fathoms. Temp. 42° F.

Antedon dentata.

Station 54. Lat. 59° 56′ N., long. 6° 27′ W. 363 fathoms. Temp. 31°·4 F.

Antedon dentata.

Station 55. Lat. 60° 4′ N., long. 6° 19′ W. 605 fathoms. Temp. 29°·8 F.

Antedon dentata.

Station 57. Lat. 60° 14′ N., long. 6° 17′ W. 632 fathoms. 30°·5 F.

{ *Antedon eschrichti.*
Myzostoma gigas.

Station 74. Lat. 60° 39′ N., long. 3° 9′ W. 203 fathoms. Temp. 47°·6 F.

Antedon dentata.

Stations unknown.

Antedon rosacea, var.

{ *Antedon hystrix.*
{ *Myzostoma cirriferum.*

H.M.S. "Porcupine." 1870.

Station 13. Lat. 40° 16′ N., long. 9° 37′ W. 220 fathoms. Temp. 52° F.

* { *Antedon phalangium.*
{ *Myzostoma alatum.*

Station 17. Lat. 39° 42′ N., long. 9° 43′ W. 1095 fathoms. Temp. 39°·7 F. Ooze.

Pentacrinus wyville-thomsoni.

Station 17*a*. Lat. 39° 39′ N., long. 9° 39′ W. 740 fathoms. Temp. 49°·3 F.

Antedon dentata.
**Antedon lusitanica.*

Station 31. Lat. 35° 56′ N., long. 7° 6′ W. 477 fathoms. Temp. 50°·5 F. Clay.

**Actinometra pulchella.*

Off Cape Sagres. 45 fathoms.

**Antedon phalangium.*

Off Carthagena. 80 fathoms.

**Antedon phalangium.*

Bay of Benzert. 50 to 100 fathoms.

Antedon phalangium.
**Antedon rosacea* (young).

Skerki Bank. 30 to 120 fathoms.

Antedon phalangium.
**Antedon rosacea* (young).

II. *The Crinoids obtained by H.M.SS. "Knight Errant" and "Triton,"* 1880–82.

1. *Rhizocrinus lofotensis*, M. Sars.

H.M.S. "Knight Errant," 1880. Station 5. Lat. 59° 26′ N.,

long. 7° 19′ W. 515 fathoms. Temp. 45·4° F. Mud. Two young specimens without arms.

Station 6. Lat. 59° 37′ N., long. 7° 19′ W. 530 fathoms. Temp. 46°·5 F. Grey mud. A fragment only.

2. *Antedon rosacea*, Linck, sp.

H.M.S. "Knight Errant," 1880. In 53 fathoms on the plateau N.N.W. of North Rona. Lat. 59° 12′ N., long. 5° 57′ W. Rough ground.

One mutilated individual was obtained here. It closely resembles the "Porcupine" variety from an unknown locality, both of them having the first brachials shorter than usual and a better developed backward projection of the second brachials. The "Porcupine" specimen, which is the better preserved, has a somewhat more robust appearance than is generally presented by this species, and looks altogether as if its habitat were in the cold area.

3. *Antedon petasus*, Dub. and Kor., sp.

A single but tolerably perfect example of this well-known Scandinavian type was obtained by the "Triton" at a depth of 87 fathoms on the Faeroe Banks (Dredging Station No. 3. Lat. 60° 39′ 30″ W., long. 9° 6′ W. Sand and shells. Temp. 49° F.). It was officiating as host to no less than eighteen individuals of *Myzostoma cirriferum*, F. S. Leuckart.

4. *Antedon dentata*, Say, sp.

H.M.S. "Triton," 1882. Station 2. Lat. 59° 37′ 30″ N., long. 6° 49′ W. 530 fathoms. Temp. 46°·2 F. Mud. Five mutilated specimens, the disc varying in diameter from 2·5 to 4 mm.

Station 5. Lat. 60° 11′ 45″ N., and 60° 20′ 15″ N., long. 8° 15′ W. and 8° 8′ W. 433–285 fathoms. Hard ground; stones. Temp. 43°·5 to 40°·8 F.

The calices and arm-bases of two individuals were obtained here. The larger one, with a disc 6·5 mm. in diameter, does not reach the size of some of the specimens dredged by the "Blake" off the coast of New England.

Attached to the disc of each was an example of von Graff's new

species *Myzostoma carpenteri*. That on the smaller individual was the larger of the two (2·3 mm.), almost rivalling its host in diameter.

Even the smallest of these seven individuals has fully developed ovaries; but it is only in the largest that the cirri exceed 10 mm. in length, and are composed of more than twenty joints.

This species was taken by the "Porcupine" both in the warm and in the cold areas.

5. *Antedon eschrichti*, Müll. sp.

H.M.S. "Triton," 1882. Station 4. Lat. 60° 22′ 40″ N. and 60° 31′ 15″ N., long. 8° 21′ W. and 8° 14′ W. 327 to 430 fathoms. Temp. 31°·5 to 30° F. Stones; mud.

A small but singularly interesting example of this well-known Arctic type. The cirri are small and comparatively delicate, not exceeding 20 mm. in length; and the arm-bases are but slightly tubercular. All the arms have been broken either at the second (8th) or third syzygy (12th or 13th brachial).

One can therefore study the appearance presented by the new arm-joints in various stages of growth. The lowest and therefore oldest of these new joints are most like those of the corresponding part of the arm in the adult, *i.e.*, triangular or very slightly quadrate, but relatively long in proportion to their width. These characters, however, do not disappear as they do in the adult, where the joints gradually become shorter and shorter, with a markedly triangular outline. But throughout the remainder of the restored arms the joints are quadrate and relatively long; while the two lowest pinnule-joints show but few traces of the flattening and peculiarities of outline which are so characteristic of the adult. It is just in these characters (besides the smaller size of the third pair of pinnules) that *Antedon quadrata* (No. 7) differs from *Ant. eschrichti*; and it is therefore to be regarded as a permanently immature form of the latter species.

6. *Antedon hystrix*, sp. n.

H.M.S. "Triton," 1882. Station 4. Lat. 60° 22′ 40″ N. and 60° 31′ 15″ N., long. 8° 21′ W. and 8° 14′ W. 327 to 430 fathoms. Temp. 31°·5 to 30° F. Stones; mud.

The single individual obtained here has been already described together with those previously dredged by the "Porcupine" (*ante*, p. 365).

7. *Antedon quadrata*, P. H. Carpenter, 1883.

Formula, $A . 10 . \frac{c}{b} .$

1877. *Antedon celticus*, von Marenzeller, *Wiener Denkschr.*, Bd. xxxv. p. 24 (separate copy).

1881. *Antedon celtica*, Sladen, *Mem. Arct. Echinod.*, p. 75.

1881. *Antedon celtica*, P. H. Carpenter, *Zool. Anzeig.*, Jahrg. iv. p. 520.

Non *Antedon celticus* of Barrett, Norman, Wyv. Thomson, &c.

Special Marks.—The lower arm-joints (after the twelfth) as long or slightly longer than wide and slightly quadrate in outline, though sometimes triangular. Those in the middle of the arm are distinctly quadrate, the length bearing a large proportion to the breadth; and the later ones are somewhat elongated. But none of the joints are shaped like an isosceles triangle, and much shorter than wide.

The third pair of pinnules (on 6 and 7 br.) are little more than half as long as the second pair; and the basal joints of the lower pinnules have their dorsal edges more or less produced into sharp flattened processes.

H.M.S. "Triton," 1882. Station 4. Lat. 60° 22′ 40″ N. and 60° 31′ 15″ N., long. 8° 21′ W. and 8° 14′ W. 327 to 430 fathoms. Stones; mud. Temp. 31°·5 to 30°. One good specimen.

Station 6. Lat. 60° 9′ N., long. 7° 16′ 30″ W. 466 fathoms. Stones. Temp. 29°·5 F. Two mutilated individuals and one fragment.

Remarks.—This species has caused me no little trouble. The first example of it known to science was dredged in 1872 by the ill-fated "Tegetthof" 5° west of Nova Zembla. It was minutely described by von Marenzeller * five years afterwards and referred to

* "Die Coelenteraten, Echinodermen, und Würmer der k. k. österreichisch-ungarischen Nordpol-expedition," *Densch. d. Wien. Akad.*, Bd. xxxv. p. 25 (of separate copy).

Antedon celticus, Barrett sp., of which only a very poor description had ever been published. In the meantime I had met with a specimen off Disco, when in the "Valorous" with Dr Gwyn Jeffreys (1875), and I recognised it at once as distinct from an *Ant. eschrichti* obtained during the same cruise. Three other examples were dredged by Fielden in the "Alert" a few months later, two at Discovery Bay (lat. 81° 41′ N.), and one at Franklin Pierce Bay (lat. 79° 25′ N.); and when the "Challenger" *Comatulæ* came into my hands I found the same type among a quantity of individuals of *Ant. eschrichti*, from a dredging in 51 fathoms a little to the south of Halifax. I have little doubt that it was also obtained by the "Vega." The "Willem Barents" met with it in 1880 near the locality of the Tegetthof dredging. Fielden's specimens were well and carefully described by Sladen,* who identified them with that dredged by the "Tegetthof," so far as he could judge from von Marenzeller's description of the latter. Thanks to the kindness of Dr von Marenzeller, I have been enabled to examine his type for myself, and I am satisfied that Sladen was right in identifying it with those dredged by the "Alert." After writing his description of them Sladen saw for the first time some examples of *Ant. celtica*, Barrett sp., and recognising that these were totally different from the Arctic specimens, he inserted a note to that effect, but did not rename the latter.

Barrett's type now turns out to be the long but little known *Antedon phalangium* of the Mediterranean; and the specific designation *celtica* being therefore unoccupied, I thought at first that it might conveniently be retained for the type described under this name by von Marenzeller and Sladen respectively.† This, however, has seemed undesirable for many reasons; and in compliance with the wishes of both the above named naturalists, I propose to give it a new name altogether. I have, therefore, chosen one indicative of the character by which the species is most easily distinguished from *Ant. eschrichti*, viz., the markedly quadrate shape of the middle and outer arm-joints, as has been noted above among the "special marks" of *Ant. quadrata*.

* *A Memoir on the Echinodermata of the Arctic Sea to the West of Greenland*. London, 1881, p. 75, pl. vi. figs. 5, 6.

† "Note on the European *Comatulæ*," *Zool. Anzeiger*, Jahrg. iv. p. 520.

This type was doubtless met with by the "Porcupine" in 1869, somewhere or other in the cold area. But there were no examples of it in the remains of the collection of *Comatulæ* which have come into my hands. The "Triton" dredgings increase its bathymetrical range down to 466 fathoms, the "Valorous" Station in Davis Strait (410 fathoms), having been the deepest hitherto known. The three "Triton" specimens are all of them small, like those of the "Tegetthof" and "Valorous"; while they have a stiffer and less feathery appearance than the larger ones obtained farther north by the "Alert" and "Willem Barents." In fact, they more nearly resemble the small individual figured by Sladen * in their general characters. The dorsal processes on the lower joints of the basal pinnules are less prominent than usual; while the peculiar characters of the first two pinnule-joints in the outer parts of the arms are by no means so marked as in larger individuals. This feature is one which is more or less visible in all the Arctic species, reaching its best development in *Ant. eschrichti.*

Station List of Crinoids and Myzostomida, 1880–82.

H.M.S. "Knight Errant." 1880.

Station 5. Lat. 59° 26′ N., long. 7° 19′ W. 515 fathoms. Mud. Temp. 45°·4 F.

Rhizocrinus lofotensis.

Station 6. Lat. 59° 37′ N., long. 7° 19′ W. 530 fathoms. Grey mud. Temp. 46°·5 F. (Fragment only.)

Rhizocrinus lofotensis.

Aug. 4. On the plateau N.N.W. of North Rona. Lat. 59° 12′ N., long. 5° 57′ W. Rough ground.

Antedon rosacea, var.

H.M.S. "Triton." 1882.

Station 2. Lat. 59° 37′ 30″ N., long. 6° 19′ W. 530 fathoms. Mud. Temp. 46°·2 F.

Antedon dentata.

Station 3. August 8, on the Faeroe Banks. Lat. 60° 39′ 30″ N., long. 9° 6′ W. 87 fathoms. Sand and shells. Temp. 49° F.

$\left\{\begin{array}{l}\textit{Antedon petasus.}\\ \textit{Myzostoma cirriferum.}\end{array}\right.$

* *Mem. Arct. Echinod.*, pl. vi. figs. 5, 6.

Station 4. Lat. 60° 22′ 40″ N. and 60° 31′ 15″ N., long. 8° 21′ W. and 8° 14′ W. 327 to 430 fathoms. Stones; mud. Temp. 31° 5′ to 30° F.

Antedon quadrata.
Antedon eschrichti.
Antedon hystrix.

Station 5. Lat. 60° 11′ 25″ N. and 60° 20′ 15″ N., long. 8° 15′ W. and 8° 8′ W. 433 to 285 fathoms. Hard ground; stones. Temp. 43°·5 to 40°·8 F.

{ *Antedon dentata.*
{ *Myzostoma carpenteri.*

Station 6. Lat. 60° 9′ N., long. 7° 26′ 30″ W. 466 fathoms. Stones. Temp. 29°·5 F.

Antedon quadrata.

III. *On the Myzostomida of the "Porcupine" and "Triton" Dredgings.* By Prof. L. von Graff, Ph.D.

A. "Porcupine" Specimens.

1. *Myzostoma cirriferum*, F. S. Leuck.

Seven individuals were found on two examples of *Antedon hystrix*, P. H. Carpenter, probably from the cold area. This is a new host, the species having been hitherto met with only on *Ant. rosacea.* It has since been found on *Ant. petasus* as well.

2. *Myzostoma gigas*, Lütken, MS.

Hab. *Antedon eschrichti.* Station 57. Lat. 60° 14′ N., long. 6° 17′ W. 632 fathoms. Temp. 30°·5 F.

Two individuals were obtained, but in such a distorted condition that they cannot be accurately determined. As, however, the numerous *Myzostomida* infesting *Ant. eschrichti* at the most widely separated localities invariably belong to this species, those obtained by the "Porcupine" are probably of the same type. It will be fully described in the "Challenger" Report.

3. *Myzostoma alatum*, sp. n.

Hab. *Antedon phalangium.* The Minch. August 14, 1869. 60 to 80 fathoms.

Station 13, 1870. Lat. 40° 16′ N., long. 9° 37′ W. 220 fathoms. Temp. 52° F.

A species belonging to the type of *Myzostoma glabrum.* Dorsal surface arched and the ventral one hollowed, with a small muscular prominence in the centre. It is unprovided with cirri, and not transparent at the margin. Mouth ventral and cloacal papilla dorsal as in *M. glabrum.* Colour dirty yellow. Parapodia extremely short and reduced to annular folds, from the middle of which there project the brownish-black points of well-developed hooklets. These are closely grouped around the central muscular prominence; while the round suckers lie near the edge of the ventral surface.

A fully grown individual, 4 mm. in diameter, was so firmly attached to the disc of its host near the mouth that the hooklets remained in the perisome when it was removed. On its back was a young one measuring 1 mm. in its longer diameter. This differs from the adult in the presence of distinct papillæ on the dorsal surface, separated from one another by considerable intervals.

4. *Myostoma pulvinar*, sp. n.

Hab. *Antedon phalangium.* The Minch. August 14, 1869. 60 to 80 fathoms.

This species has a very singular form. It is transversely oval, 3·2 mm. wide and 2·7 mm. long; and it is thicker than any other free-living species. The dorsal surface is flat, while the ventral one is raised like a cushion, with the parapodia projecting round its edge at equal distances apart, as wide and blunt processes, at the points of which powerful hooklets are protruded for some distance. There are no suckers; while the mouth and cloacal openings, usually situated on the same side as the parapodia, are placed on the dorsal surface. Both this and the ventral surface are of a strong yellow brown colour. The only specimen obtained was closely attached to the perisome of its host. No other *Myzostomida* but *M. pulvinar* and *M. alatum* are known to infest *Antedon phalangium.*

B. "Triton" specimens.

1. *Myzostoma cirriferum*, F. S. Leuckart.

Hab. *Antedon petasus.* Station 3. Lat. 60° 39′ 30″ N., long. 9° 6′ W. 87 fathoms. Sand and shells. Temp. 49° F.

The single individual of *Ant. petasus* obtained at this station was harbouring no less than eighteen examples of this species, some adult and some young. It may have therefore yet another host besides *Ant. rosacea* and the new *Ant. hystrix* of the "Porcupine" dredgings. It has also been found on a specimen of *Ant. petasus* from Norway, in P. H. Carpenter's own collection; and likewise on another Norwegian example (from Arendal) in the University Museum at Kiel. No other species of *Myzostoma* is as yet known to infest *Ant. petasus.*

2. *Myzostoma carpenteri*, sp. n.

Hab. *Antedon dentata.* Station 5. Lat. 60° 11′ 45″ N. and 60° 20′ 15″ N., long. 8° 15′ W. and 8° 8′ W. 433 to 285 fathoms. Hard ground; stones. Temp. 43°·5 to 40°·8 F.

I have dedicated this species to my friend Dr P. H. Carpenter. It is of a dirty yellow colour, 2·3 mm. long, and of slightly greater width. Twenty short cirri appear at its margin, which is without a transparent rim. In fact, the whole disc is firm and opaque. The form of the ventral surface is most unusual, and there is no trace of the muscular prominence which is so generally present in its centre. This would indicate that the parapodial musculature is very weak. The parapodia themselves are extremely slender and short, being lodged in shallow pits close to the edge of the ventral side, and almost on the same level with the equally feeble suckers. Both mouth and cloacal opening are terminal. Attached to the dorsal surface of one of the two adults was an immature individual ·46 mm. long. The very characteristic differences betw en the two will be given in the "Challenger" Report, together with the specific diagnoses. This is the only species of *Myzostoma* which has yet been found infesting *Antedon dentata*, better known as *Antedon sarsii;* and it is as yet only known from the "Triton" dredgings.

5. On the Structure of the Pitcher in the Seedling of *Nepenthes*, as compared with that in the Adult Plant. By Professor Alexander Dickson, M.D.

Preliminary Note.

The only observations, so far as I am aware, that have been made on the pitchers of *Nepenthes* seedlings, are those by Sir J. D. Hooker, who, in 1859, described their external configuration in his paper "On the Origin and Development of the Pitchers of *Nepenthes*, &c.," in vol. xxii. of the Linnean Society's *Transactions*, and afterwards added a few details of anatomical structure, in his admirable address on Insectivorous Plants, delivered at the Belfast meeting of the British Association in 1874.

This year I have had opportunitiy of examining *Nepenthes* seedlings from a large crop which our Botanic Garden Curator, Mr Lindsay, has raised from seeds of a female plant of *N. rafflesiana*, fertilised by pollen from *N. Chelsoni* (itself a hybrid).

In these seedlings the small lanceolate cotyledons are immediately succeeded by pitcher-leaves, which in form, as pointed out by Hooker, on the whole more closely resemble the pitchers of *Sarracenia*, than those of the adult *Nepenthes*. We have the entire leaf hollowed out into a funnel-shaped pitcher, with two largely developed wing-like expansions, and with a remarkably ciliated lid, whose base extends round fully one half of the orifice of the pitcher, very much as in *Sarracenia*, and very unlike the condition in the adult *Nepenthes*, where the *annulus* occupies almost the whole of the pitcher-orifice, the base of the lid being narrowed into a very small space. Our seedlings also exhibit, what Hooker has described, the convergence of the lateral wings towards each other above, and their union in the middle line, forming a transverse ciliated membrane below the orifice of the pitcher.

As regards further details, our seedlings differ somewhat from those described by Hooker. In the first place, Hooker describes (Belfast address) the inner surface of the pitcher as wholly glandular, while in our plants its upper half, or so, is eglandular and conducting, being thickly studded with the characteristic downwardly directed crescentic ledges. This difference between the two

seedlings may be easily accounted for, inasmuch as there are some species of *Nepenthes* in which the entire inner surface of the pitcher is glandular (*e.g.*, *N. ampullaria* and *N. Hookeri*), and his seedlings may have belonged to some such species. The occurrence, indeed, of such a large conducting surface in the pitchers of our hybrid, is somewhat surprising when its origin is considered. In the *female* parent, *N. rafflesiana*, the conducting surface is limited to an inconsiderable area below the hinge of the lid; which area, when traced round the upper part of the pitcher, is seen to be reduced to a very narrow stripe, just below the line of inflexion of the annulus; while in the *male* parent, *N. Chelsoni*, there is practically no conducting surface at all, there being nothing left of it but the merest trace, running along below the said line of inflexion. The only suggestion I can make on the subject is that there may here be a reversion to some ancestor of the cross-bred *N. Chelsoni*. The following table represents the rather complicated genealogy of our seedlings, so far as ascertained:—

Nepenthes rafflesiana × *Nepenthes* sp.
|
N. Dominii × *N. Hookeri*
|
N. rafflesiana × *N. Chelsoni*
|
Our Hybrid.

It will be observed that the male parent of *N. Dominii* has not been recorded. On examining this form (which closely resembles *N. rafflesiana* in the limitation of its conducting surface), I have been struck with the great breadth and almost horizontal expansion of the *reflexed* portion of the annulus; and I would suggest that perhaps *N. Veitchii*, which seems (I only know of this plant by figure) to exhibit this character to a still more marked degree, may have been the parent in question.

In the second place, Hooker describes the first developed pitchers of his seedlings as destitute of annulus (*Linn. Soc. Trans.*, xxii. p. 418, footnote); while in ours this structure is very readily recognised, even in the leaf immediately succeeding the cotyledons, by its epidermis of imbricately disposed glassy cells, and its inflexion within the pitcher-orifice. As to this, I should almost be inclined

to believe that the supposed absence of annulus was the result of an oversight, so distinctly developed is it in my specimens; not to speak of its universal occurrence in the adult *Nepenthes* plant.

Regarding the anatomical structure of these pitchers, there are several interesting points to note.

A. The *Pitcher-lid.*—This exhibits ciliary processes each tipped with a cell-group resembling that of a glandular hair. These processes, however, seem to be somewhat more than mere epidermal appendages, at least containing ground-tissue, as evidenced by the occurrence of the curious spiral cells which are developed so extensively in the ground tissue of these plants; and possibly they may represent prolongations of the entire leaf substance, like the tentacles of *Drosera.* Furthermore, there is no trace of the honey-glands which are to be seen on the lid of the adult form in both its parents; and in connection with this, it is interesting to note the absence of lid-glands in the adult of *N. ampullaria*, which species may thus be considered as exhibiting the undifferentiated or embryonic character.

B. The *Annulus.*—This is quite distinctly marked, and may be traced by its characteristically imbricate epidermis from just above the transverse membrane joining the wings up to the pitcher-orifice, where it is inflected as a slightly crenated margin. The most interesting feature of the *annulus*, however, is the presence, just within the inflexed margin, of small cushion- or button-like glands, resembling in general character the glands of the secreting surface in the lower part of the pitcher-cavity. In the first leaf and those immediately succeeding it, these glands are usually *three* in number (in one specimen I have seen only *two*). In the subsequently developed leaves they become more numerous, and in our seedlings now about a year old, as many as twenty of these glands may be counted along the margin of a pitcher about an inch long. They form a very pretty circlet—or rather semi-circlet—reminding one of the row of ocelli in an *Actinia.* The presence of these glands in the annulus, coupled with the absence of lid-glands, at once arrested my attention, and led me to suppose that here we probably had structures of greater morphological significance and of more universal occurrence than the glands of the lid, since these glands—physiologically important as they undoubtedly are—are not necessarily present in the adult plant. I have accordingly examined the annulus of a number

of adult forms, and in this I have to acknowledge much valuable co-operation from my assistant, Dr J. M. Macfarlane. The result has almost surpassed my expectations. In all the species examined there is to be seen, immediately above the edge of the inflexed margin, a single line of small orifices alternating with the ridges of the corrugated annulus, and with their tooth-like prolongations when these are present. These orifices are the openings of canal-like fossæ, from the bottom of each of which a cellular nipple-like process or mammilla projects. These mammillæ are the apices of what may be termed the *Marginal Glands.* The glands are of very large size; the smallest I have seen—those of *N. ampullaria*—being $\frac{1}{37}$ of an inch in length, while in some other forms—*e.g.*, *N. destillatoria*, *N. phyllamphora*, and an undetermined form (apparently allied to the hybrid *N. Dominii*), for which our Garden was indebted to the late Miss Hope of Wardie, they may reach the enormous length of $\frac{1}{12}$ of an inch. The nipple-like apex just mentioned is never more than about $\frac{1}{200}$ of an inch in length, and is the only portion of the gland which is free, all the rest being immersed in the parenchymatous substance of the annulus. The cells composing these glands are of somewhat small size, and are very numerous. Those in the immersed portion are, in a general way, disposed in lines which pass obliquely inwards and towards the apex, the peripheral cells having a more or less transverse direction, while the central ones are longitudinally disposed. The superficial cells of the mammilla exhibit a beautiful columnar arrangement, being elongated at right angles to the surface. In some cases, especially in the larger forms, there seems to be a tendency to the formation of a central cavity from disruption from each other of the longitudinally disposed cells in the axis; but I should not be inclined to attach any physiological significance to this circumstance. In shape the marginal glands vary somewhat. In *N. ampullaria* the shape is ampullate, the nipple-like apex representing the neck, while the immersed portion, somewhat pointed at the base, and broadening upwards, represents the body of the ampulla. In the more elongated forms the shape is more or less cylindrical or sausage-like.

The marginal glands, it will be seen, are remarkable not only for their large size, but still more for their immersed condition—the

other glands of *Nepenthes* (lid-glands as well as peptic ones) projecting entirely free from the surface, covered in though they may be by a pocket-like flap, or sunk at the bottom of a surface depression. In their *immersed* character, the marginal glands are perfectly comparable to the immersed glands of the secreting surface of the pitcher of *Cephalotus.* As to the function of these marginal glands, I cannot as yet speak definitely. Sir Joseph Hooker says (Belfast Address) that the pitcher-margins of *Nepenthes* always secrete honey; but from his making no allusion to these very remarkable glands, I am doubtful whether he refers to them or not. Probably, however, they are honey-secreting, and afford to the insect the last drops, just as it is on the brink of destruction.

C. The *Conducting* surface.—This agrees essentially with that in the adult forms. I have here to note that each crescentic ledge consists of a single semilunar cell, which overlaps a lower and smaller cell. Occasionally these two cells somewhat puzzlingly resemble deformed stomata, but I have not as yet been able to trace a more definite relation in this direction.

D. The *Secreting* or *Digestive* surface.—The epidermis cells here are remarkable for their wavy outlines, differing from the more angular form exhibited in the adult plants of the parent forms. The glands, moreover, are in the first-formed leaves entirely exposed, although in the later ones the rudiment of the protective pocket-like flap may be seen. In this connection Dr Macfarlane has pointed out to me that in *N. phyllamphora* the peptic glands are only to a very slight extent covered by flaps, so that in this plant we have the persistence of an embryonic character. In the first pitchers of the seedling the peptic glands are few in number—about ten; but in the later developed ones they become very numerous.

PROCEEDINGS

OF THE

ROYAL SOCIETY OF EDINBURGH.

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Monday, 7th January 1884.

THOMAS STEVENSON, Esq., Vice-President, in the Chair.

The following Communications were read :—

1 Approximation to the Roots of Cubic Equations by help of Recurring Chain Fractions. By Edward Sang.

(*Abstract.*)

In the progression of fractions here used, each new term is got by corresponding multiples of the three preceding terms, thus:

$$rA + qB + pC = D\,,$$
$$rB + qC + pD = E\,,$$
$$rC + qD + pE = F\,, \text{ and so on,}$$

this mode of formation being applied separately to the numerators and denominators of the fractions.

For the cube root of 2 there is given the progression

$$\frac{1}{0}, \frac{0}{0}, \frac{1}{1}, \frac{4}{3}, \frac{15}{12}, \frac{58}{46}, \frac{223}{177}, \text{ \&c,} \qquad = \sqrt[3]{2}$$

for which the multipliers are $r = 1$, $q = 3$, $p = 3$, and also a more rapidly converging series

$$\frac{-1}{0}, \frac{0}{0}, \frac{5}{4}, \frac{286}{227}, \frac{16287}{12927}, \text{ \&c.} \qquad = \sqrt[3]{2}$$

having the multipliers 1, -3 and 57.

The cube root of 7 is given by the progression

$$\frac{-2}{1}, \frac{0}{0}, \frac{44}{23}, \frac{66658}{34846}, \frac{100986738}{52791621}, \&c. \qquad = \sqrt[3]{7}$$

formed by the multipliers 1 , − 3 , 1515.

And, in general, the ratio sub-triplicate of that expressed by any two integer numbers K and L, is shown to be the asymptote of the progression formed by the multipliers

$$r = (L - K)^6 ; \; q = 3(L - K)^4 ; \; p = 3L^2 + 21KL + 3K^2 ;$$

from the initials

$$\frac{+(L-K)^{-3}}{-(L-K)^{-3}}, \; \frac{0}{0}, \; \frac{K+2L}{2K+L}.$$

The asymptote of every progression of this kind is shown to be the root of a cubic equation; while, for every cubic equation with integer coefficients, such progressions may be found. Thus the corresponding theorem in quadratics, which was thought to exclude periodicity from all higher equations, becomes only one case of a general law.

In addition to the progression for the ratio of the long diagonal to the side of a regular heptagon, given in a former paper, that having the multipliers 1 , 4 , 3 is given thus,

$$\frac{1}{0}, \frac{0}{0}, \frac{2}{1}, \frac{7}{3}, \frac{29}{13}, \frac{117}{52}, \frac{474}{211}, \&c.,$$

and for the corresponding ratio in the case of the enneagon,

$$\frac{-1}{0}, \frac{0}{0}, \frac{3}{1}, \frac{26}{9}, \frac{216}{75}, \frac{1791}{622}, \&c.,$$

having the multipliers 1, − 6 , 9.

It is also shown that terms placed at equal intervals in such progressions form separate progressions of the same kind; this law applying also to the ordinary periodic continued fractions approximating to the roots of quadratics

2. The Researches of M. E. de Jonquières on Periodic Continued Fractions. By Thomas Muir, M.A.

1. During the present year there has appeared at intervals, in the *Comptes Rendus* of the French Academy, quite a series of communications by M. E. de Jonquières, on the subject of those periodic continued fractions which are the equivalents of the square roots of integers. These communications have attracted attention, both on account of the number of results given in them, and because, as a writer in the *Bulletin des Sciences Mathématiques* says, of their interesting and profound character. To any one really intimate with the bibliography of the subject, this cannot but be a little surprising. It is true that the number of so-called theorems is great; but the very special character of a number of them, the fact that they are just such theorems as may be obtained by experiment and induction, and the want of demonstrations of them as evidence that the author was in possession of a mathematical theory of the subject, are points that have been too much overlooked. Further, and what is more important, many of the theorems are not new, and there is a sense in which the epithet " new " cannot fairly be applied to any of the earlier ones, because of the existence of a widely general theorem in which they are directly included, or from which they may with readiness be deduced.

2. It is to this general theorem I now wish to direct attention, making use of it for the purpose indicated, viz., of giving scientific order and unity to M. de Jonquières' work. The theorem was given in the year 1873, in the first paper I had the honour of communicating to this Society, and is to be found at p. 234 of vol. viii. of the *Proceedings.* It, as well as several other theorems given in the paper, was originally accompanied by a good deal of detail of the same nature as M. de Jonquières' theorems; these special propositions, however, were struck out, when by request an abstract of the paper was prepared for printing. A special case of the theorem has been rediscovered twice at least since 1873; the latest appearance being in Grunert's *Archiv,* lxix. pp. 205–13, where the writer, K. E. Hoffmann, says regarding it:—"Diese allgemeine Formel enthält nun alle in der Stern'schen Tabelle gegebenen als specielle Fälle in sich, welche durch passende Wahl der z_1, z_2, etc. aus der

hier gegebenen abgeleitet werden können." When it is recalled that Stern's memoir extends to 102 pages of Crelle's *Journal*, the magnitude of the generalisation will be appreciated.

3. The statement of the special case referred to (which is all that is needed for our present purpose) is as follows :—" *The general expression for every integer whose square root, when expressed as a continued fraction with unit numerators, has* $q_1, q_2, \ldots, q_2, q_1$, *for the symmetric portion of its cycle of partial denominators is*

$$\left\{\tfrac{1}{2}K(q_1, q_2, \ldots, q_2, q_1)M - (-1)^l \tfrac{1}{2}K(q_1, q_2, \ldots, q_2)K(q_2, \ldots, q_2)\right\}^2$$
$$+ K(q_1, \ldots, q_2)M - (-1)^l K(q_2, \ldots, q_2)^2,$$

l being the number of elements in the cycle."

The functional symbol K( ) is explained by the example

$$K(a, b, c, d) \equiv \begin{vmatrix} a & 1 & 0 & 0 \\ -1 & b & 1 & 0 \\ 0 & -1 & c & 1 \\ 0 & 0 & -1 & d \end{vmatrix}.$$

4. Taking the case then of this theorem where $l = 2$, we have

$$\sqrt{(\tfrac{1}{2}qM)^2 + M} = \tfrac{1}{2}qM + \frac{1}{\underset{*}{q}} + \frac{1}{\underset{*}{qM}} + \ldots \qquad (M > 1)$$

the asterisks indicating the beginning and end of the cycle. This is M. de Jonquières' first theorem.

It is desirable to state it in two parts, viz., (1) where q is even $= 2k$ say, (2) where M is even, $= 2N$ say. These give

$$\left.\begin{aligned} \sqrt{(kM)^2 + M} &= kM + \frac{1}{\underset{*}{2k}} + \frac{1}{\underset{*}{2kM}} + \cdots \qquad (M > 1) \\ \sqrt{(qN)^2 + 2N} &= qN + \frac{1}{\underset{*}{q}} + \frac{1}{\underset{*}{2qN}} + \cdots \end{aligned}\right\} \quad \text{(I.)}$$

By giving all possible integral values to k, M, q, N here, we obtain every number whose square root has a cycle of two terms, and at the same time we obtain the said cycle. The condition, $M > 1$, is necessary to prevent degeneration of the cycle; if $M = 1$, the cycle is

$$\underset{*}{\frac{1}{2k}} + \underset{*}{\frac{1}{2k}} + \cdots \quad i.e., \quad \underset{*}{\frac{1}{2k}} + \cdots$$

5. When $l = 4$ the general theorem gives us

$$\sqrt{\left\{\tfrac{1}{2}(q_1^2 q_2 + 2q_1)\text{M} - \tfrac{1}{2}(q_1 q_2 + 1)q_2\right\}^2 + (q_1 q_2 + 1)\text{M} - q_2^2}$$

$$= \{\quad\} + \underset{*}{\frac{1}{q_1}} + \frac{1}{q_2} + \frac{1}{q_1} + \underset{*}{\frac{1}{2\{\quad\}}} + \cdots \qquad \text{(II}'\text{)}$$

where for shortness there is put

$$\{\quad\} \text{ for } \{\tfrac{1}{2}(q_1^2 q_2 + 2q_1)\text{M} - \tfrac{1}{2}(q_1 q_2 + 1)q_2\}.$$

Here again a little consideration, based on the knowledge that the number under the root-sign must be integral, serves to show that there are two distinct cases, viz.,

(1) when q_2 is even,

(2) when q_2 is odd, q_1 odd, and M even.

Putting therefore in the first case $q_2 = 2k$, and in the second case $q_2 = 2s - 1$, $q_1 = 2r - 1$, $\text{M} = 2\text{N}$, we have as our pair of identities

$$\text{(II.)}\begin{cases} \sqrt{\left\{(kq^2+q)\text{M} - (2kq+1)k\right\}^2 + (2kq+1)\text{M} - 4k^2} \\ \qquad = \{\quad\} + \underset{*}{\frac{1}{q}} + \frac{1}{2k} + \frac{1}{q} + \underset{*}{\frac{1}{2\{\quad\}}} + \cdots \qquad \text{M} > \frac{2k}{q} \\ \sqrt{\left\{(8r^2s - 8rs - 4r^2 + 8r + 2s - 3)\text{N} - (2rs - r - s + 1)(2s-1)\right\}^2 + 2(2rs - r - s + 1)\text{N} - (2s-1)^2} \\ \qquad = \{\quad\} + \underset{*}{\frac{1}{2r-1}} + \frac{1}{2s-1} + \frac{1}{2r-1} + \underset{*}{\frac{1}{2\{\quad\}}} + \cdots \end{cases}$$

These give every integer whose square root has a four-termed cycle, and make known the cycle as well.

Returning now to (II′) and putting $q_1 = 1$, we have

$$\sqrt{\{\tfrac{1}{2}(q+2)\text{M} - \tfrac{1}{2}(q+1)q\}^2 + (q+1)\text{M} - q^2}$$

or

$$\sqrt{\{\tfrac{1}{2}(q+2)\text{M} - \tfrac{1}{2}(q+1)q + 1\}^2 - (\text{M} - q + 1)}$$

or

$$\sqrt{\{\tfrac{1}{2}(q+2)(\text{M} - q + 1)\}^2 - (\text{M} - q + 1)}$$

$$= \left\{\tfrac{1}{2}(q+2)(\text{M} - q + 1) - 1\right\}^2 + \underset{*}{\frac{1}{1}} + \frac{1}{q} + \frac{1}{1} + \underset{*}{\frac{1}{2\{\quad\}}} + \cdots$$

where, to prevent degeneration of the cycle, we must have

$$\left\{\quad\right\} \overline{\gtreqless} q$$

$$i.e., \ (q+2)\text{M}-(q+1)q \overline{\gtreqless} 2q$$

$$\therefore (q+2)\text{M} \overline{\gtreqless} q^2+3q$$

$$\therefore \qquad \text{M} \overline{\gtreqless} q+\frac{q}{q+2}$$

$$\text{and} \qquad \therefore \qquad \text{M}>q.$$

Writing N for $\text{M}-q+1$, this special result becomes

$$\sqrt{\left\{\tfrac{1}{2}(q+2)\text{N}\right\}^2-\text{N}}=\left\{\tfrac{1}{2}(q+2)\text{N}-1\right\}^2+\underset{*}{\frac{1}{1}}+\frac{1}{q}+\frac{1}{1}+\underset{*}{\frac{1}{2\{\quad\}}}+\ldots \quad (\text{N}>1)$$

which is the accurate form of M. de Jonquières' second theorem. M. de Jonquières' oversight consists in omitting to notice that the g in his statement must be less than $a+1$.

6. Theorem III. is avowedly a combination of theorems I. and II.; it is carefully stated, however, in such a way as to seem to support M. de Jonquières' theory that the number of terms in the cycle of the continued fraction for $\sqrt{a^2+d}$ is dependent upon the ratio of $2a:d$.

7. Theorem IV. there is no accounting for; it is but a case of theorem II., viz., where $b=2n+4$ and $e=4$. Neither is there any accounting for the remark following it—"Le nombre 12, qui devrait figurer en tête de la série, fait seul exception, parce qu'il rentre dans le groupe défini par le théorème I, à cause de $12=3^2+3$"; for 12 is the case where $n=0$, and there could be no continued fraction with the cycle 1, 0, 1, $2a$. If it be an exception, then a whole class of exceptions to theorem II. has been overlooked, viz., where $q=2$.

8. When $l=5$, the general theorem gives

$$\sqrt{\left\{\tfrac{1}{2}(p^2q^2+2pq+p^2+1)\text{M}+\tfrac{1}{2}(pq^2+p+q)(q^2+1)\right\}^2+(pq^2+p+q)\text{M}+(q^2+1)^2}$$
$$=\left\{\quad\right\}+\underset{*}{\frac{1}{p}}+\frac{1}{q}+\frac{1}{q}+\frac{1}{p}+\underset{*}{\frac{1}{2\{\quad\}}}+\ldots$$

Here also there are two cases, viz.,

(1) q odd, M even, $=2k+1$, 2N say,

(2) q even, p even, M even, $=2r$, $2s$, 2N say,

the corresponding identities being

(III.)

$$\sqrt{\left[\{(4p^2k^2+4kp^2+4pk+2p^2+2p+1)\text{N}+(4pk^2+4pk+2p+2k+1)(2k^2+2k+1)\}^2 + (4pk^2+4pk+2p+2k+1)2\text{N}+(4k^2+4k+2)^2\right]}$$

$$=\{\quad\}+\frac{1}{\underset{*}{p}}+\frac{1}{2k+1}+\frac{1}{2k+1}+\frac{1}{p}+\frac{1}{2\underset{*}{\{\quad\}}}+\ldots$$

$$\sqrt{\left[\{(16r^2s^2+8rs+4r^2+1)\text{N}+(4rs^2+r+s)(4s^2+1)\}^2+(4rs^2+r+s)4\text{N}+(4s^2+1)^2\right]}$$

$$=\{\quad\}+\frac{1}{\underset{*}{2r}}+\frac{1}{2s}+\frac{1}{2s}+\frac{1}{2r}+\frac{1}{2\underset{*}{\{\quad\}}}+\ldots$$

Putting in the first of these $k=0$, we have

$$\sqrt{\{2p^2+2p+1)\text{N}+2p+1\}^2+(2p+1)2\text{N}+4}$$

$$=\{\quad\}+\frac{1}{\underset{*}{p}}+\frac{1}{1}+\frac{1}{1}+\frac{1}{p}+\frac{1}{2\underset{*}{\{\quad\}}}+\ldots$$

Specialising still further by taking $\text{N}=0$, we have

$$\sqrt{(2p+1)^2+4}=(2p+1)+\frac{1}{\underset{*}{p}}+\frac{1}{1}+\frac{1}{1}+\frac{1}{p}+\frac{1}{2\underset{*}{(2p+1)}}+\ \ldots$$

which is M. de Jonquières' theorem V., and which is to be found given as an example at page 31 of my pamphlet on *The Expression of a Quadratic Surd as a Continued Fraction*, Glasgow, 1874.

9. Considerable interest attaches to the above identity deduced from (III.) by putting $k=0$. Written in the unexpanded form of the general theorem, it is

$$\sqrt{\{\text{K}(p,1,1,p)\text{N}+\tfrac{1}{2}\text{K}(p,1,1)\text{K}(1,1)\}^2+\text{K}(p,1,1)2\text{N}+\text{K}(1,1)^2}$$

$$=\{\quad\}+\frac{1}{\underset{*}{p}}+\frac{1}{1}+\frac{1}{1}+\frac{1}{p}+\frac{1}{2\underset{*}{\{\quad\}}}+\ldots$$

Now

$$\begin{aligned}&\text{K}(p,1,1,p)\text{N}+\tfrac{1}{2}\text{K}(p,1,1)\text{K}(1,1)\\ &=\text{K}(p,1,1,p)\text{N}+\text{K}(p,1,1)\\ &=\text{K}(p,1,1,p,\text{N});\end{aligned}$$

and

$$\begin{aligned}&\mathrm{K}(p,1,1)2\mathrm{N}+\mathrm{K}(1,1)^2\\ &=2\{\mathrm{K}(p,1,1)\mathrm{N}+\mathrm{K}(1,1)\}\\ &=2\mathrm{K}(1,1,p,\mathrm{N}).\end{aligned}$$

The identity may therefore be put in the form

$$\sqrt{\mathrm{K}(p,1,1,p,\mathrm{N})^2+2\mathrm{K}(1,1,p,\mathrm{N})}=\{\ \}+\frac{1}{\overset{*}{p}}+\frac{1}{1}+\frac{1}{1}+\frac{1}{p}+\frac{1}{\overset{*}{2\{\ \}}}+\dots$$

But

$$\mathrm{K}(p,1,1,p,\mathrm{N})\div\mathrm{K}(1,1,p,\mathrm{N})=p+\frac{1}{1}+\frac{1}{1}+\frac{1}{p}+\frac{1}{\mathrm{N}};$$

and thus we have the curious theorem,—

If the periodic continued fraction for $\sqrt{\mathrm{A}^2+2d}$ (d prime to A) *be wanted and the continued fraction equivalent to* $\mathrm{A}\div d$ *be found to be of the form* $p+\frac{1}{1}+\frac{1}{1}+\frac{1}{p}+\frac{1}{\mathrm{N}}$, *then the periodic continued fraction required is* $\mathrm{A}+\frac{1}{\overset{*}{p}}+\frac{1}{1}+\frac{1}{1}+\frac{1}{p}+\frac{1}{\overset{*}{2\mathrm{A}}}$.

Example—

$$\sqrt{338}=\sqrt{18^2+14}=18+\frac{1}{\overset{*}{2}}+\frac{1}{1}+\frac{1}{1}+\frac{1}{2}+\frac{1}{\overset{*}{36}}+\dots$$

$$\begin{aligned}\text{for }\frac{18}{7}&=2+\frac{4}{7},\\ &=2+\frac{1}{1}+\frac{1}{1}+\frac{1}{3},\\ &=2+\frac{1}{1}+\frac{1}{1}+\frac{1}{2}+\frac{1}{1}.\end{aligned}$$

10. Taking the case of the general theorem where $l=6$, we have

$$\begin{aligned}&\sqrt{[\{\tfrac{1}{2}(a^2b^2c+2abc+2a^2b+2a+c)\mathrm{M}-\tfrac{1}{2}(ab^2c+bc+2ab+1)(b^2c+2b)\}^2}\\ &\qquad+(ab^2c+bc+2ab+1)\mathrm{M}-(b^2c+2b)^2]\\ &\qquad=\{\ \}+\frac{1}{\overset{*}{a}}+\frac{1}{b}+\frac{1}{c}+\frac{1}{b}+\frac{1}{a}+\frac{1}{\overset{*}{2\{\ \}}}+\dots\end{aligned}$$

Here the only case which is not possible is a, b, c, all odd: that is to say, we may have

(1) a odd, c even.

(2) b even, c odd.

(3) a even, c even, M even.

(4) a even, b odd, c odd, M even.

As a particular case of the first of these particular cases, let us take $a=1$, $c=2$, $\mathrm{M}=2b^2+1$. Then

$$\sqrt{4(b+1)^2+4b+1} = 2(b+1) + \frac{1}{\underset{*}{1}+}\,\frac{1}{b+}\,\frac{1}{2+}\,\frac{1}{b+}\,\frac{1}{1+}\,\frac{1}{\underset{*}{4(b+1)}+}\cdots$$

This is M. de Jonquières' Theorem VI., and was given by me as a chance example in 1874 (see p. 31 of *The Expression of a Quadratic Surd, &c.*).

11. Having enunciated these six theorems, M. de Jonquières adds:—"Les théorèmes I, II et III montrent, comme je l'avais annoncé, que la longueur et la composition de la période dépendent principalement de la valeur du rapport $2a \div d$ quand cette valeur est entière, et tous mettent en évidence ce fait que, dans une même *famille* de nombres, ceux des termes de la période qui changent d'un nombre à l'autre sont de la seule variable." This mode of reasoning is somewhat perplexing. Being concerned with functions of any number of variables, M. de Jonquières takes the functions in the ultimate or penultimate stage of specialisation, and tries to draw general conclusions from the results thus obtained. Such a course could not but be futile. Knowing, as we do, that, $q_1, q_2, \ldots, q_2, q_1$ being the terms of the symmetric portion of the cycle, the expression for M. de Jonquières' $2a$ is

$$\mathrm{K}(q_1,q_2,\ldots,q_2,q_1)\mathrm{M} - (-1)^l\mathrm{K}(q_1,q_2,\ldots,q_3,q_2)\mathrm{K}(q_2,\ldots,q_2)\,,$$

and for his d,

$$\mathrm{K}(q_1,\ldots,q_2)\mathrm{M} - (-1)^l\mathrm{K}(q_2,\ldots,q_2)^2\,,$$

we have instantaneously forced on us the conclusion that for the solution of our problem something besides the *ratio* of $2a$ to d must be taken into account. Not only, however, does M. de Jonquières merely direct his attention to very special cases, but these special cases are specially selected; special cases that tell a different story are ignored. What simple peculiarity, we may ask, of the ratio $2a:d$ exists for the infinite number of other special cases of our

identity (II.) besides M. de Jonquières' special case? And when the ratio $2a:d$ remains constant, because of a varying as d, is no alteration made in the extent of the cycle? Surely M. de Jonquières, from actual observation, knows as well as any one that if merely $2a \div d$ be constant, the *general rule* is that the cycle *varies* in extent, and that the case where it does not vary (M. de Jonquières' theorem I.), instead of being the *rule*, is the *exception.* Then, again, M. de Jonquières forces into his service facts which are manifestly against him. He says theorems I., II., III. bear out a certain conclusion. Now III., as we have seen, shows nothing that I. and II. do not show, and need not therefore have been referred to; and Theorem II. shows something totally different from Theorem I. In Theorem II. the ratio considered is not $2a:d$, but $2b:e$, *i.e.*, $2(a+1):2a-d+1$. This theorem is, therefore, not a support to M. de Jonquières' theory, but the opposite.

As for M. de Jonquières' second fact, which, as he says, all his six theorems bear out, we can only meet it by asking in what sense it is possible seriously to talk of q_1 or q_2 as being functions of

$$K(q_1, q_2, \ldots, q_2, q_1)\mathrm{M} - (-1)^l K(q_1, q_2, \ldots, q_2) K(q_2, \ldots, q_2).$$

Had M. de Jonquières confined himself to refuting Lagrange's statement that the extent of the cycle in the expansion of $\sqrt{E}$ depends only on the value of E, he would have been on safe ground, for the incorrectness of the statement has long been known, and indeed must have been known, one would think, to Lagrange himself; the only conclusion, however, beyond this, to which his researches entitle him, is the vague one that it depends somehow, as Lagrange also said, "de la *nature* du nombre E."

12. Having, in order to follow M. de Jonquières, considered the cases of the general theorem where $l = 2, 4, 5, 6$, it seems desirable for the sake of continuity to put on record the details of the omitted case, viz., where $l = 3$. The theorem then becomes

$$\sqrt{\left\{\tfrac{1}{2}(q^2+1)\mathrm{M} + \tfrac{1}{2}q\right\}^2 + q\mathrm{M} + 1} = \{\quad\} + \frac{1}{\underset{*}{q}}\,\frac{1}{+q}\,\frac{1}{+2\underset{*}{\{\quad\}}} + \ldots$$

It is readily seen, however, that in order to avoid fractions, q and

M must both be even: putting therefore $q = 2p$ and $\mathrm{M} = 2\mathrm{N}$, we have as our final result for the case

$$\sqrt{\{(4p^2+1)\mathrm{N}+p\}^2+4p\mathrm{N}+1} = \{\quad\} + \frac{1}{\underset{*}{2p}+}\,\frac{1}{2p+}\,\frac{1}{\underset{*}{2\{\quad\}}+}\,\ldots$$

This furnishes a theorem closely resembling that in § 9. For here M. de Jonquières' ratio—

$$\begin{aligned} &= \frac{2(4p^2+1)\mathrm{N}+2p}{4p\mathrm{N}+1} \\ &= 2p + \frac{2\mathrm{N}}{4p\mathrm{N}+1} \\ &= 2p + \cfrac{1}{2p+\cfrac{1}{2\mathrm{N}}}\,. \end{aligned}$$

Hence,

If the periodic continued fraction for $\sqrt{\mathrm{A}^2+d}$, *(*d *prime to* A*), be wanted, and the continued fraction equivalent to* $2\mathrm{A} \div d$ *be found to be of the form* $2p + \frac{1}{2p+}\,\frac{1}{2\mathrm{N}}$, *then the periodic continued fraction required is* $\mathrm{A} + \frac{1}{\underset{*}{2p}+}\,\frac{1}{2p+}\,\frac{1}{\underset{*}{2\mathrm{A}}+}\,\ldots$

13. These two theorems, as might be inferred, are not isolated from the main subject; and it is of importance to see their exact position in the theory, not merely on their own account, but because this can be done by establishing a general theorem, which affords a complete solution of the problem M. de Jonquières set himself, viz., to find what relation exists between the ratio $2a : d$ and the terms of the cycle.

We have seen that

$$2a = \mathrm{K}(q_1, q_2, \ldots, q_2, q_1)\mathrm{M} - (-1)^t\mathrm{K}(q_1, q_2, \ldots, q_2)\mathrm{K}(q_2, \ldots, q_2)$$

and $\therefore$ writing C for $(-1)^{t+1}\mathrm{K}(q_2, \ldots, q_2)$ we have

$$2a = \mathrm{M}\mathrm{K}(q_1, \ldots, q_1) + \mathrm{C}\mathrm{K}(q_1, \ldots, q_2),$$

$$= \begin{vmatrix} q_1 & 1 & 0 & \ldots & 0 & 0 & 0 \\ -1 & q_2 & 1 & \ldots & 0 & 0 & 0 \\ 0 & -1 & q_3 & \ldots & 0 & 0 & 0 \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & 0 & \ldots & q_2 & 1 & 0 \\ 0 & 0 & 0 & \ldots & -1 & q_1 & \mathrm{C} \\ 0 & 0 & 0 & \ldots & 0 & -1 & \mathrm{M} \end{vmatrix}.$$

Similarly $d = \mathrm{K}(q_1, \ldots, q_2)\mathrm{M} - (-1)^l\mathrm{K}(q_2, \ldots, q_2)^2$,

$$= \mathrm{MK}(q_1, \ldots, q_2) + \mathrm{CK}(q_2, \ldots, q_2),$$

$$= \begin{vmatrix} q_2 & 1 \ldots & 0 & 0 & 0 \\ -1 & q_3 \ldots & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 \ldots & q_2 & 1 & 0 \\ 0 & 0 \ldots & -1 & q_1 & \mathrm{C} \\ 0 & 0 \ldots & 0 & -1 & \mathrm{M} \end{vmatrix}.$$

But this determinant is the complementary minor of the element in the place (1, 1) of the former determinant: hence by the fundamental application of continuants,

$$\frac{2a}{d} = q_1 + \cfrac{1}{q_2 + \cfrac{1}{q_3 + \ddots + \cfrac{1}{q_2 + \cfrac{1}{q_1 + \cfrac{(-1)^{l-1}\mathrm{K}(q_2, \ldots, q_2)}{\mathrm{M}}}}}}$$

Our theorem thus is—

If $\sqrt{a^2 + d} = a + \frac{1}{\overset{*}{q_1}} + \frac{1}{q_2} + \cdots + \frac{1}{q_2} + \frac{1}{q_1} + \frac{1}{\overset{*}{2a}} + \cdots$

then $\frac{2a}{d} = q_1 + \frac{1}{q_2} + \cdots + \frac{1}{q_2} + \frac{1}{q_1} + \frac{(-1)^{l-1}\mathrm{K}(q_2, \ldots, q_2)}{\mathrm{M}}$

where l *is the number of terms of the cycle and* M *some integer or zero.*

When l is odd and $\mathrm{K}(q_2, \ldots, q_2)$ has certain special values, a converse of this is possible: and it is thus that the theorems in §§ 9, 12 originate.

Additional Note.

(Ordered by the Council to be printed in sequence to Mr Muir's former Note.)

On the 3d April 1883, M. Catalan presented to the Belgian Royal Academy a paper on continued fractions and certain series.

At the end of the abstract of it published in the Academy's *Bulletin* (p. 612–618) there is the following

"Addition.

"Un Géomètre bien connu, M. de Jonquières, vient de présenter, à l'Académie des sciences, un travail intitulé : *Note sur un point de la théorie des fractions continues périodiques.* Les théorèmes, très intéressants, auxquels l'honorable auteur est parvenu, m'ont fait revenir sur mes précédentes recherches. Malheureusement, je n'ai pu rédiger encore cette *Addition :* le temps m'a fait défaut. Afin de prendre date, j'énonce le théorème suivant, qui contient, comme cas particuliers, quelques-uns des résultats obtenus par M. de Jonquières.

Soient $\frac{P'}{P}$, $\frac{Q}{P}$ *les deux dernières réduites de la fraction continue, symétrique :*

$$b,\ c,\ d,\ \ldots,\ d,\ c,\ b.$$

Soient a, α, *deux nombres entiers, satisfaisant aux conditions :*

$$Q\alpha - 2Pa = P', \quad (\alpha < 2a).$$

Si l'on fait

$$A = a^2 + \alpha$$

les racines carrées de tous les nombres A (*il y en a une infinité*) *sont données par la formule*

$$\sqrt{A} = a(b,\ c,\ d,\ \ldots,\ d,\ c,\ b,\ 2a)."$$

I desire to point out that this theorem also is not new, and that, indeed, when pushed to its proper conclusion it gives the theorem above referred to as having been rediscovered by Hoffmann.

When asked for an expression giving all the integers whose square roots have the cycle $b,\ c,\ d,\ \ldots,\ d,\ c,\ b,$ M. Catalan replies that the expression is

$$a^2 + \alpha,$$

where a and α are integral solutions of the indeterminate equation

$$Q\alpha - 2Pa = P',$$

Q standing for $(b,\ c,\ \ldots,\ c,\ b)$, P for $(b,\ c,\ \ldots c)$ and P′ for $(c,\ \ldots,\ c)$.

Now there is no need for giving the answer in this imperfect and

roundabout fashion: the equation referred to can readily be solved. For it is clear that

$$\frac{2Pa+P'}{Q} \text{ must be integral:}$$

and as P is prime to Q, this is the same as saying that

$$\frac{2P^2a+PP'}{Q} \text{ must be integral.}$$

But $P^2=QP'+(-1)^l$ if l be the number of terms in the cycle $(b, c, \ldots, c, b)$. Hence

$$\frac{2aQP'+2a(-1)^l+PP'}{Q}=\text{an integer.}$$

$$\therefore \qquad \frac{(-1)^l 2a+PP'}{Q}=\text{an integer}=\textsc{m} \text{ say}$$

$$\therefore \qquad a=(-1)^l\tfrac{1}{2}\{Q\textsc{m}-PP'\}.$$

By substitution now in the original equation we find

$$\alpha=(-1)^l\{P\textsc{m}-P'^2\}.$$

Hence the required expression is

$$\tfrac{1}{4}\{Q\textsc{m}-PP'\}^2+(-1)^l(P\textsc{m}-P'^2).$$

M. Catalan's equation, the solution of it here given, and this final result, are to be found in the *The Expression of a Quadratic Surd*, &c., p. 30.

3. New Forms of Nerve Terminations in the Skin of Mammals. By George Hoggan, M.B. (Edin.). Communicated by Professor Turner.

(*Abstract.*)

The new forms have been found in the palms of the raccoon, the *Procyon lotor*, so named from its habit of dipping its morsels in water before eating them. These forms are three in number, and, in order to prevent any morphological or physiological appellation being applied to them, they have been named, for purposes of description and differentiation, after three ladies respectively, the Browne, the Hoggan, and the Blackwell bodies. The Browne bodies occupy the apices of the dermic papillæ, exactly where the

Meissner bodies are found in man, monkeys, and marsupials; otherwise they have no resemblance to these bodies. Properly speaking, they are not bodies, but only forked terminations of the nerves, formed generally of two or three prongs, and these are twisted and intertwined in an intricate manner. Nor do they possess any capsular envelopes, the presence of which differentiates them from the Hoggan bodies, that being the only distinct difference between the two.

The Hoggan bodies in their external aspect resemble the Pacinian bodies, being provided with a greater or less number of capsular layers, according to the greater or less depth at which they lie in the dermis. The nerve terminations within the body are, however, quite distinct from anything yet found in the Mammalia, being in general branched immediately after the nerve has become enveloped in the capsules. In their branched and contorted form the nerve terminations resemble the Browne bodies plus the capsules they have received. It is probable that the Browne bodies are formed by rupture of some of the non-medullated nerve fibres forming the subepidermic plexus, a little beyond the point where a medullated nerve has joined the plexus. These ruptured fibres contract upon themselves, and thus form the Browne body. As the Browne body sinks more deeply into the dermis it seems to receive the cellular envelopes which characterise the Hoggan body.

The Blackwell body is a modified subepidermic nerve ganglion, still attached to the epidermis, but of which all the cells get compressed into a more or less globular or oval form, and are all in connection with a very thick medullated nerve. It is indeed a modified Meissner body within the epidermis in its most complete form, but a subepidermic ganglion in its simplest forms. It is a midway link between these two organs.

The Browne and Hoggan bodies seem to be homologous with the forked nerve endings on the hair follicles, and so far they support the author's previously published views that the Pacinian bodies are only modifications of the forked endings.

In most of the sections the sweat glands seem to be greatly deficient in number, and as the author has in other animals, especially rodents, observed Meissner bodies to be only developed where the sweat glands were enormous in size and number, he argues from

this—first, that moisture is necessary to give proper sensation; second, that the deficiency of sweat makes the animal dip its morsels in water; and third, that this continual wetting of the hands has modified the nerve terminations.

4. Diagnoses plantarum novarum Phanerogamarum Socotrensium, etc.; quas elaboravit Bayley Balfour, Scientiæ Doctor et in Universitate Glascuensi rerum botanicarum regius Professor. Pars quarta (Supplementum).

CRUCIFERÆ.

Brassica rostrata, *Balf. fil.*, var. hirsuta, *Balf. fil.*: omnino hirsuta foliisque arcte dentato-serratis.

Socotra, in montibus crescens. B.C.S. No. 555.

CAPPARIDEÆ.

Cleome brachycarpa, *Vahl*, var. filicaulis, *Schweinf.*: minuta eglandulosa inodora filicaulis.

Socotra, prope Tamarida. Schweinf. No. 289.

Mærua angolensis, *DC.*, var. socotrana, *Schweinf.*: arbor mediocris vel frutex ramis effuso-dependentibus dense foliosis; foliis tenuiter carnosulis vel (perennantibus) crassis suberosis, petiolo duplo vel ad $\frac{1}{3}$ lamina breviore flaccido haud recurvo, lamina basi cuneata ovali-obovata v. oblongo-lineari ad apicem rotundata v. emarginata semper mucronata; floribus paucis mediocribus apetalis; fruct. ignot.

Nom. vern. Eschäb. 'Eschab. Eshaib.

Socotra, in campis montibusque. B.C.S. Nos. 193, 588. Schweinf. Nos. 251, 457, 603.

VIOLARIEÆ.

Alsodeia socotrana, *Balf. fil.*: herbacea ramosissima humilis glabra; foliis parvis ellipticis v. subobovatis brevissime petiolatis obscure remoteque serrulatis subtus glanduloso-puberulis; floribus solitariis; filamentis brevissimis.

Socotra, prope Tamarida. B.C.S. No. 26.

CARYOPHYLLEÆ.

GYPSOPHILA MONTANA, *Balf. fil.*, var. VISCIDA, *Balf. fil.*: robustior inflorescentiæ ramis ultimis brevioribus et omnino pilis glandulosis vestita.

Socotra, in montibus. B.C.S. No. 554. Schweinf. No. 658.

Distrib. Somali Land.

POLYCARPÆA SPICATA, *Arn.*, var. CAPILLARIS, *Balf. fil.* : tenuior pauciramosa; foliis paucis filiformibus; bracteolis siccis rufis marginibus vix scariosis.

Socotra, prope Galonsir. B.C.S. No. 211. Schweinf. No. 239.

ZYGOPHYLLEÆ.

FAGONIA CRETICA, *Linn.*, var. SOCOTRANA, *Balf. fil.* : omnino inarmata glauca ramis striatis scabrido-hispidis; foliis unifoliatis crassis ovato-ellipticis v. ellipticis v. rotundatis v. suborbicularibus $\frac{2}{3}$–$1\frac{1}{6}$ poll. longis $\frac{5}{21}$–$\frac{5}{6}$ poll. latis; stipulis minutis $\frac{1}{12}$ poll. longis subulatis submembranaceis; pedunculis sub capsulis dilatatis et eis subæquilongis; sepalis subpapillosis ; petalis albidis v. purpureis; capsulis pubescentibus ; seminibus obsolete punctulatis.

Socotra, abundans. B.C.S. No. 202.

GERANIACEÆ.

DIRACHMA, *Schweinf.*

Flores regulares. Calyx 8-partitus, lobis valvatis. Petala 8, perigyna, imbricata. Glandulæ disci inconspicuæ. Stamina 8, libera, petalis opposita, omnia antherifera; antheræ magnæ, oblongæ. Ovarium 8-lobum, 8-loculare, rostratum; stylus centralis, integer, obtusus; ovula in loculis solitaria, adscendentia. Capsula 8-loba, in carpella 8 ventraliter dehiscentia intus lanata secedentia. Semina compressa, in loculis solitaria; testa nitida; albumen sparsum.—Frutex ramosus, plusminusve pubescens. Folia alterna, dentato-serrata, paullo revoluta, stipulata. Pedunculi axillares, 1-flori. Flores albi. Calyx 4-bracteatus.

Genus monotypicum generibus Wendtiæ Balbisiæ et Vivianiæ Americanibus australibus maxime affine.

D. SOCOTRANA, *Schweinf.*: species unica in montibus Haghier crescens. B.C.S. Nos. 285, 344. Schweinf. No. 528.

LEGUMINOSÆ.

TEPHROSIA (Brissonia) ODORATA, *Balf. fil.*: herbacea parva plusminusve strigosa; foliis digitatim trifoliatis; foliolis vix $\frac{1}{2}$ poll. longis oblanceolatis; stipulis minutis; floribus solitariis axillaribus odoratis purpureis.

Socotra, in montibus calcareis prope Galonsir. B.C.S. No. 180.

ACACIA PENNIVENIA, *Schweinf.*: arbor ramis glabris fuscis; foliis glaberrimis 2–3–pinnatis glandulis nullis, foliolis laxe 7–9-jugis oblongo-obovatis nervo fusco medio dimidiatis venis utrinque 3–4-pinnatis; floribus albis in capitula racemum laxum formantia v. subpaniculata dispositis, involucello infra medium basin versus pedunculi griseo-tomentosi subcaduco; calycis lobis rotundato-ciliatis; corolla calyce dimidio longiore; staminibus exsertis; legumine ignoto.

Nom. vern. Tamhor.

Socotra, in montibus crescens. B.C.S. Nos. 212, 345. Schweinf. Nos. 459, 519. Hunt. No. 17.

CUCURBITACEÆ.

EUREIANDRA BALFOURII, *Cogn.*: caule glabro; petiolo brevissime sparseque puberulo demum glabro; foliis utrinque breviter sparseque asperis demum albo-callosis, plerumque leviter 3–5-lobatis, lobis saepius triangularibus, apice subacutis; floribus pro genere parvis, masculis brevissime racemosis subfasciculatis; calycis tubo late infundibuliformi subcampanulato; staminum filamentis glabris; ovario oblongo; fructu ovoideo-subfusiformi, apice longiuscule acuteque rostrato.

Nom. vern. Dachshana v. Dichshani.

Socotra, per insulam crescens. B.C.S. No. 281. Schweinf. Nos. 502, 541, 640, 647.

FICOIDEÆ.

TETRAGONIA PENTANDRA, *Balf. fil.*: glabra ramis longe patentibus; foliis deltoideo-ovatis remotis; floribus binis axillaribus; staminibus quot tot calycis lobis; nucamento pentagono obconoideo.

Socotra, prope Galonsir. B.C.S. No. 37.

RUBIACEÆ.

DIRICHLETIA OBOVATA, *Balf. fil.*, var. ALBESCENS, *Balf. fil.*; ramis albescentibus; foliis ad ramulos laterales contractos plurimis confertis lanceolatis v. oblanceolatis acutis valde revolutis crassiusculis; floribus sæpe solitariis; pedicellis longissimis tenuibus; calyce in fructu plerumque concavo.

Nom. vern. Sehat.

Socotra, in campis prope Galonsir. B.C.S. No. 592. Schweinf. No. 250.

PLACOPODA VIRGATA, *Balf. fil.*, var. NANA, *Balf. fil.*: nana ramis validioribus et ramulis brevibus prostratis; foliis plerumque minoribus paucioribus et solum 2–5 in quoque fasciculo obovatis crassiusculis.

Socotra, in campis. B.C.S. No. 86.

HEDYOTIS PULVINATA, *Balf. fil.*: pulvinata congesta; foliis parvis anguste acinaciformibus crassis triquetris imbricatis; stipulis connatis fimbriatis; floribus sessilibus axillaribus solitariis; stylo bifido.

Socotra, prope Galonsir abundans. B.C.S. Nos. 15, 719. Schweinf. No. 716.

HEDYOTIS BICORNUTA, *Balf. fil.*: annua minuta plantaginea; foliis aggregatis linearibus basi in stipulas connatas paucifimbriatas expansis revolutis minute papillosis; floribus axillaribus sessilibus solitariis; stylo bifido; fructu compresso vertice bifido bicornuto septicide dehiscente; seminibus foveolatis angulatis.

Socotra, prope Galonsir. B.C.S. No. 178.

COMPOSITÆ.

HELICHRYSUM GRACILIPES, *Oliv. & Hiern*, var. LANATUM, *Balf. fil.*: dense lanatum, pedunculis brevibus, acheniis glabris

Socotra, prope Tamarida. Schweinf. No. 327

HELICHRYSUM GRACILIPES, *Oliv. & Hiern*, var. PROFUSUM, *Balf. fil.*: foliis submembranaceis, capitulis parvis paucifloris in paniculas ramosas dispositis, pedicellis erectis.

Socotra, apud Keregnigiti. Schweinf. No. 470.

Helichrysum gracilipes, *Oliv. & Hiern*, var. stoloniferum, *Balf. fil.*: stoloniferum capitulis majoribus multifloris solitariis, phyllariis exterioribus brevibus ovatis, interioribus longis spathulatis acutis.

Socotra, in montibus prope Galonsir. B.C.S. No. 238. Nimmo.

Tripteris Lordii, *Oliv. & Hiern*, var. racemosa, *Balf. fil.*: a basi multiramosa; foliis plerumque oblanceolatis angustis; capitulis minoribus $\frac{1}{4}$ poll. longis; involucri bracteis oblongo-ellipticis acutis $\frac{1}{8}$ poll. longis; floribus flavis radii ligula $\frac{1}{8}$ poll. longa; acheniis $\frac{1}{3}$ poll. longis.

Socotra, prope Galonsir atque Tamarida abundans. B.C.S. No. 74. Schweinf. No. 443.

PLUMBAGINEÆ.

Vogelia indica, *Gibs.*, var. socotrana, *Balf. fil.*: omnino tenuior; foliis minoribus sæpe vix perfoliatis et retusis; inflorescentia multo pseudo-furcatim ramosissima, racemis ultimis 1–2 poll. longis; bracteolis lanceolatis; sepalis anguste lanceolatis margine membranaceis superne obscure transverse bullato-undulatis, inferne truncatis; corollæ limbo sinu apicali vix mucronulato.

Nom. vern. Salepho.

Socotra in montibus Haghier. B.C.S. No. 416. Schweinf. Nos. 406 in lit., 523.

EBENACEÆ.

Euclea laurina, *Hiern*: fruticosa; foliis ellipticis v. obovatis suboppositis v. oppositis apice plus minusve rotundatis basi cuneatis breviter petiolatis supra intense viridibus; racemis axillaribus; floribus 4- rarissime 3-meris; corollâ anguste cylindratâ breviter lobatâ.

Socotra, in montibus Haghier et apud Galonsir. B.C.S. Nos. 166? 383.

Euclea Balfourii, *Hiern*: fruticosa; foliis ovalibus v. obovatis oppositis v. suboppositis apice rotundatis basi plus minusve angustatis demum plerisque obtusis undulatis supra viridibus infra

rubentibus resinoso-lepidotis; racemis masculis axillaribus; floribus 4-meris; corollâ latâ campanulatâ.

Socotra, in montibus Haghier. B.C.S. No. 167. Schweinf. No. 644.

ACANTHACEÆ.

Ruellia patula, *Jacq.*, var. pubescens, *Balf. fil.*: dense pubescens, foliis obtusis subrotundis.

Socotra. B.C.S. No. 579. Schweinf. No. 614.

Distrib. Nile Land.

Ruellia patula, *Jacq.*, var. minor, *Balf. fil.*: nana canescens, foliis floribusque parvulis; corolla vix $\frac{1}{2}$ poll. longa; fructu $\frac{1}{4}$ poll. longo; seminibus $\frac{1}{2}$ poll. diam.

Socotra. B.C.S. Nos. 270, 728.

Anisotes diversifolius, *Balf. fil.*, var. brevicalyx, *Balf. fil.*: foliis apice angustatis, calycis lobis brevibus $\frac{1}{12}$ poll. longis.

Socotra, in montibus Haghier. B.C.S. No. 479.

LABIATÆ.

Teucrium petiolare, *Balf. fil.*, var. pubescens, *Balf. fil.*: pubescens non incanum ramis folia majora gerentibus.

Socotra, in montibus Haghier. Schweinf. No. 578.

GENUS ANOMALUM.

Wellstedia, *Balf. fil.*

Flores hermaphroditi regulares. Calyx alte 4-partitus, persistens, tubo basi ovario adnato, lobis angustis acutis æqualibus extus adpresse rigide pilosis. Corolla hypocrateriformis, tubo cylindraceo extus intusque glabro sub fructu a basi sursum in segmenta 4 rumpente, limbi lobis 4 ovatis v. deltoideo-ovatis æqualibus extus adpresse pilosis imbricatis. *Stamina* 4, æqualia, angulis corollæ loborum inserta, filamentis liberis subulatis incurvis corollæ lobis paulum brevioribus; antheræ cordato-rotundatæ v. suborbiculares,

2-loculares, loculis parallelis introrsis rima longitudinali, dorso affixæ. Discus 0. Ovarium 2-carpellatum, 2-loculare, compressum, integrum, parte triente infera, inferne glabrum, superne basin styli circum dense albido-setosum; stylus validus, calycis lobis subæquilongus, adpresse rigide pilosus, bifidus, stigmatibus parvis terminalibus; ovula anatropa, in loculo quoque solitaria (plerumque in uno abortivum?), ab placentis sub apice septi medii affixis pendula, funiculo brevi. Capsula oblique subobcordata, inæqualiter bilobata, complanata, bilocularia, loculo majore vacuo, angusti-septata, loculicide dehiscentia, valvis coriaceis a septo crustaceo tenui uninervio in loculum vacuum convexo semenque amplectente secedentibus, extus adpressis rigidis pilis vestita. Semen solitarium, septo pendulum, complanatum, obliquum, superne truncatum, inferne acutum, testa tenui comosa; embryo magnus, cotyledonibus carnosis ovatis plano-convexis accumbentibus radicula longioribus, radicula supera tereti, albumine nullo.—Suffrutex pulvinatus, parvus, ramis congestis, omnino pilis rigidis adpressis vestitus. Folia alterna, subimbricata, anguste spathulata v. obovata, obtusa. Stipulæ 0. Flores in axillis sessiles, spicas unilaterales breves formantes.

Genus monotypicum anomalum pluribus notis Boragineis et Verbenaceis maxime affine, ab illis fructu capsulari ovuloque pendulo differt, ab his ob cotyledones accumbentes, radiculam superam, foliorum characteres habitumque exclusum.

W. SOCOTRANA, *Balf. fil.*: species unica in campis Socotræ Insulæ crescens. B.C.S. No. 569. Hunter.

ILLECEBRACEÆ.

HAYA, *Balf. fil.*

Flores hermaphroditi, parvi, ad nodos glomerati, bracteis scariosis stipuliformibus involucrati. Perianthium 5-partitum, album; segmenta æqualia, oblonga, obtusa, mutica, erosa v. emarginata, tenuia, enervia, basi subcrassa. Stamina 5, basi segmentorum inserta, staminodiis minutissimis alternantia, filamentis subulatis; antheræ

biloculares. Ovarium parvum, trigonum, membranaceum; stylus filiformis, elongatus, stigmate capitellato; ovulum solitarium, basilare, erectum, anatropum, funiculo longo tereti. Fructus tenuis, basim versus in valvas tres dehiscens. Semen erectum, ellipsoideum, testa crustacea; embryo dorsalis, albumine farinaceo applicitus, leviter curvatus, radicula infera.—Herba, diffuse divaricatim ramosa, glabra. Folia sessilia, 3-verticellata, obovata, apiculata, integerrima; stipulæ minutæ, ovatæ, acuminatæ, scariosæ. Flores sessiles in dichasia brevia secunda oppositifolia et axillaria conferti. Bracteæ parvæ, fusco-brunneæ, scariosæ.

Genus monotypicum, Illecebro ipso affine.

H. OBOVATA, *Balf. fil.*: species unica in montibus Socotræ frequens. B.C.S. No. 250. Schweinf. No. 554.

LOCHIA, *Balf. fil.*

Flores consimiles bracteis scariosis noninvolucratis. Perianthium herbaceum, demum induratum, 5-lobum, tubo brevissimo obconico angulato fauce disco tenui annulari instructa; lobi conniventes, ovato-oblongi, firmi, dorso infra apicem mucronati. Stamina 5, perigyna, cum staminodiis setosis alternantia, filamentis brevibus; antheræ parvæ oblongæ. Ovarium ellipsoideum, liberum; stylus filiformis apice bifidus; ovulum amphitropum, funiculo basilari erecto longiusculo complanato suspensum. Utriculus membranaceus, demum basi ruptus. Semen ab apice funiculi suspensum, inversum, compressum, testa membranacea.—Fruticulus rigidus, salsoloideus, diffusus, caulibus tortis, ramulis intricatis nodosis. Folia opposita et in axillis fasciculata, sessilia, anguste lanceolata v. spiculiformia, integerrima, crassa; stipulæ breves, interpetiolares connatæ, hyalinæ. Flores parvi, in dichasia breviter ramosa terminalia bracteis obtegentibus majoribus membranaceis brunneis dispositi, sessiles.

Genus monotypicum in sectione Paronychiearum positum et generi Gymnocarpos affine.

L. BRACTEATA, *Balf. fil.*: species unica in montibus Socotræ infrequens. B.C.S. No. 429.

AMARANTACEÆ.

ÆRUA LANATA, *Juss.*, var. ROBUSTA, *Balf. fil.*: dense lanata, caulibus robustis; foliis crassis magnis apice rotundatis; spicis elongatis.

Socotra, in campis. B.C.S. No. 517. Schweinf. No. 219.

EUPHORBIACÆ.

EUPHORBIA (Anisophyllum) LEPTOCLADA, *Balf. fil.*: fruticosa, ramulis ultimis delicatulis articulatis glabris; foliis omnibus oppositis parvis petiolatis ellipticis; capitulis minutis terminalibus solitariis pedicellatis; involucri glandulis inappendiculatis; staminibus paucis.

Socotra, prope Kischen. Schweinf. No. 615 partim.

EUPHORBIA (Tirucalli) SCHWEINFURTHII, *Balf. fil.*: fruticosa, ramis juvenilibus glabris; foliis sessilibus elongatis linearibus; cymis solitariis terminalibus monocephalis; involucro extus pubescente, bracteis fimbriatis, glandulis albis; staminibus paucis.

Socotra, prope Kischen. Schweinf. No. 650.

EUPHORBIA (Tirucalli) ARBUSCULA, *Balf. fil.*, var. MONTANA, *Balf. fil.*: irregulariter ramosa ramis ultimis brevibus validis, articulis brevibus; capsulis $\frac{1}{5}$ poll. longis $\frac{1}{4}$ poll. latis, pedicello $\frac{1}{4}$ poll. longo tenui; stylo in fructu brevi $\frac{1}{12}$ poll. longo; seminibus $\frac{1}{12}$ poll. longis.

Socotra, in montibus altioribus. B.C.S. No. 347. Schweinf. No. 643.

EUPHORBIA (Diacanthium) SPIRALIS, *Balf. fil.*: fruticosa carnosa candelabriformis a basi pauciramosa 1–2-pedalis, caule ramisque acute 5–7–angulatis sulcatis, angulis compressis subalatis spiraliter tortis rarius rectis lobatis lobis rotundatis parvis arcte positis, aculeis stipularibus binis brevibus $\frac{1}{6}$–$\frac{1}{5}$ poll. longis ab pulvino basali glauco divaricatis demum frequenter demissis, podariis distinctis.

Socotra, in campis frequens. B.C.S. No. 729.

Securinega Schweinfurthii, *Balf. fil.*: fruticosa, ramulis subtetragonis nonspinescentibus; foliis crassiusculis obovatis; pedicellis masculis solitariis.

Socotra, prope Wadi Digal. Schweinf. No. 562.

LILIACEÆ.

Asparagus africanus, *Lamk.*, var. microcarpus, *Balf. fil.*: suffruticosus, intricato-ramosus, cortice griseo nitido levi, ramulis anfractuosis; foliis spinosis brevibus $\frac{1}{12}$ poll. longis recurvis; floribus in umbellis, interdum paucis; baccis parvis $\frac{1}{8}$ poll. diam. pedicello brevi.

Socotra, in campis. B.C.S. No. 16. Schweinf. No. 374.

Urginea porphyrostachys, *Baker*: bulbo ovoideo; foliis hysteranthiis ignotis; scapo tereti fragili; racemo laxo elongato, pedicellis solitariis elongatis strictis erecto-patentibus, bracteis minutis lanceolatis calcaratis; perianthii parvi segmentis lanceolatis uninervatis albidis dorso late purpureo-vittatis; staminibus inclusis, filamentis glabris, antheris parvis oblongis; fructu acute angulato; seminibus in loculo 2–3 magnis nigris discoideis.

Socotra, prope Kischen. Schweinf. No. 678.

CYPERACEÆ.

Cyperus conglomeratus, *Rottb.*, var. socotranus, *Balf. fil.*: culmus rigidus erectus vix pollicaris subcompressus striatus; foliis $1\frac{1}{2}$ poll. longis culmo longioribus substrictiusculis a basi canaliculatis apice supra subplanis subtus carinatis; fasciculo spicarum solitario apicali sessili tribracteato 2–6-stachyo, bracteis inæqualibus spicis brevioribus; spicis teretibus $\frac{1}{3}$ poll. longis $\frac{1}{16}$ poll. latis, squamis arcte imbricatis ellipticis obtusis mucronatis paullo convexis superne carinulatis multinerviis basi fuscis.

Socotra, prope Galonsir. B.C.S. No. 91.

GRAMINEÆ.

Rhynchelytrum microstachyum, *Balf. fil.*, var. albicomum, *Balf. fil.*: spiculis paullo majoribus glumisque tribus exterioribus dense pilis albis sericeo-piloso-villosis.

Socotra, prope Galonsir et Tamarida. B.C.S. No. 124. Schweinf. No. 467.

5. Abstract of Report on the "Porcupine" Tunicata. By Professor W. A. Herdman.

This paper deals only with the *Ascidiæ Simplices* collected during the cruises of the "Porcupine" in the summers of 1868–1870. The *Asciidæ Compositæ* will be worked up along with the "Challenger" forms, and will appear in the second part of the Report upon the Tunicata of that expedition.

Eleven species of simple Ascidians were found in the "Porcupine" collection. There are no Clavelinidæ, but the other three families are represented—the Ascidiidæ by three species, the Cynthiidæ by five species, and the Molgulidæ by three species.

Three species (all belonging to the genus *Polycarpa*) seem new to science; the remaining eight are most of them common British species. Some of them, however, possess an interest apart from their morphological peculiarities on account of the localities and depths from which they were obtained. For example, several of the stations are in localities of which the Ascidian fauna had never been investigated, and the depths of which exceed 100 fathoms. *Styela grossularia*, van Beneden, a common British species, which is usually regarded as a littoral or shallow-water form, was obtained in the North Atlantic between Lewis and the Färoe Islands (Station 54), at a depth of 363 fathoms!

6. Arrangement of the Metals in an Electro-Frictional Scale. By A. Macfarlane, D.Sc.

While, in recent years, the progress of the science of electricity has been very rapid, few investigations have been made in the old province of frictional electricity. It cannot be doubted, however, that the laws connecting electricity with friction, and with the nature of the substances rubbed, are of great importance; and the acquisition of more detailed knowledge in this department may throw some light on the still imperfect theory of the voltaic cell. Several electricians have expressed an opinion that the development of electricity by friction is only a modification of the development of electricity by contact—that friction is contact in which the

number of points which come together is increased by sliding the one substance over the other. But whether friction is a form of contact, or contact a form of friction, or the two co-ordinate to one another, it is interesting to inquire whether the metals can be arranged in an electro-frictional series similar to the electro-contact series; and if so, to observe the relation of the former to the latter.

What is the present state of our knowledge on this subject? Experimenters have used one or other of two methods, either rubbing the metal with an insulating substance, or brushing it with a metallic powder. Observations cannot be made, or at least have not as yet been made with success, by rubbing two metals directly against one another, as their high conductivity allows the generated electricities to combine too quickly. Information on this subject is contained in the treatises of Reiss and Mascart.

Haüy,* rubbing with a woollen cloth, found that the following metals became positively electrified—

Silver, lead, copper, zinc, brass, bismuth;

while the following became negatively electrified—

Platinum, palladium, gold, nickel, iron, tin, arsenic, antimony.

Faraday,† on the contrary, using the same material for a rubber, found that silver and copper became negatively electrified. When these two are taken out of the former list, the four left—lead, zinc, brass, bismuth—are metals which are easily disintegrated; and that we shall find is the reason why they become electrified in the opposite manner from the others.

Dessaignes,‡ also rubbing with a woollen stuff, gives a wholly indefinite result,—that gold, platinum, silver, copper, iron, bismuth, zinc, tin, antimony, lead, are sometimes positive, sometimes negative, and sometimes neutral. He considered that the season of the year, the prevailing wind, the barometer, and the thermometer, all had an influence on the result. Fortunately, the subject is not so complex as this experimenter would have us believe; I have found that, provided the insulation and the state of the surfaces be attended to, the season of the year, the barometer, the thermometer, and the prevailing wind may be left out of account. It is

* *Ann. de Chim.*, vol. viii. (1818). † *Exp. Res.*, art. 2141.
‡ *Journal de Physique* (1811).

possible, however, that the state of the air as regards moisture may have some influence. If the surface of the metal is moist, or the rubber moist, the amount of electricity produced by a rub is not so great as when both are dry. This difference is due, in part at least, and it may be entirely, to the worse insulating power of the moist or moistened rubber.

Cavallo,* with sealing-wax as the rubbing material, found all the metals he tried negative; but Singer† found iron, steel, graphite, lead, and bismuth positive, the others negative. The iron, however, was positive only when rubbed with smooth wax; it was negative when rubbed with tarnished (soft ?) wax. Wilson‡ found with a silver plate, that when he rubbed the wax on the surface the plate became positive, but when he rubbed it on the edge the plate became negative. Some experiments which I have made throw light on these anomalies.

With sulphur as the rubbing material, Davy§ found that lead having a fresh surface became negative, but when it had a tarnished surface became positive. While Wilcke found all the metals negative excepting lead, Faraday found iron, copper, brass, tin, silver, and platinum positive. The contradictory results in the case of sulphur appear to be due to the presence or absence of abrasion in the rubbing, and to the presence or absence of a charge on the sulphur.

De la Rive,‖ using a variety of rubbers—the hand, ivory, horn, cork, caoutchouc, resin—found the following metals always negative—

Rhodium, platinum, palladium, gold, tellurium, cobalt, nickel;

the following mostly negative—

Silver, copper, brass;

and the following negative or positive—

Antimony, bismuth, lead, zinc, tin, iron.

He found great difficulty with his mode of friction in getting either

* *Treat. of El.*, i. 21.
† *Elem. d. Elekt.*, 21
‡ Priestley's *Hist. of El.*, 144.
§ Gilbert's *Ann.*, 28 168.
‖ *Bibliothique universelle*, 59, 13.

lead or bismuth to become positive. Hard rubbing was doubtless the cause of his anomalies also.

The method by metallic powder was employed by Singer* and Becquerel. The former experimenter allowed the powder to fall through a sieve of haircloth, flannel, or muslin. He found the powder always negative, whether it was of copper, iron, zinc, tin, bismuth, antimony, nickel, or graphite. Here the friction was gentle, and in consequence no anomaly. Becquerel† experimented with filings of copper and of zinc. He allowed the filings to fall on a slant plate (in connection with the earth), and to drop into a metallic receiver attached to the knob of an electroscope. He found that the copper filings were positive, when the plate was of

Copper, zinc, lead, tin, iron, bismuth, antimony;

and without any sensible charge when the plate was of

Platinum, gold, silver.

With zinc filings, the following were negative—

Platinum, gold, silver, copper, graphite;

and the following positive—

Zinc, iron, bismuth, antimony.

These results, so far as they go, agree very well with those I have obtained, and that agreement proves that the metals may be compared by rubbing them all with one suitable substance.

None of the investigators mentioned place the metals in a scale; Becquerel's results place them in three groups. The only scale which I have found published is a qualitative one by Gaugain. He experimented with discs of about 7 cm. diameter, formed of gutta percha, and gutta percha rubbed for a greater or less time with sulphur. He rubbed such an insulating disc with wires of the different metals; and the place of the metal was determined by the kind of electricity produced and retained on the disc. The scale or rather classification is as follows:—

Aluminium—

Gutta percha, No. 1.

* *Elem. de Elekt.*, 1819, 199. † *Ann de Chim. et de Phys.*, 47, 116.

Lead, cadmium, zinc—
Gutta percha, No. 2.

Iron, tin—
Gutta percha, No. 3.

Copper, bismuth—
Gutta percha, No. 4.

Antimony—
Vulcanised caoutchouc.

Silver—
Gutta percha, No. 5.

Platinum—
Gutta percha, No. 6.

Mercury, gold, palladium.

The upper end of the scale is the positive, and the lower end the negative.

This arrangement of the metals differs from that which results from my experiments chiefly in the position of tin, bismuth, and antimony. The positions of the latter two are contradictory to Becquerel's results.

In the experiments which I have made I have aimed at getting quantitative results. With an electroscope to scrutinise the electricity produced, only qualitative results could be looked for; but with an electrometer to scrutinise the electricity, more definite information is possible. I had the advantage of the use of a Thomson quadrant electrometer, and not only so, but of all the scientific conveniences of Professor Tait's laboratory.

The metal to be rubbed was constructed in the form of a circular disc (fig. 1), with a projecting tongue for allowing it to be screwed on to the brass top (*s*) of a glass insulator (*g*) (fig. 2). The diameter of the disc was in each case 2·5 inch (6·3 cm.), and the thickness two-tenths of an inch (5 mm.). Some of the discs varied slightly from that thickness; but a small difference in thickness does not affect the capacity of the disc, for the capacity of a disc depends only on the diameter (Clerk-Maxwell, *El. and Mag.*, vol. i. p. 222). A

small pin (h') in the brass top passed through the smaller hole (h) in the tongue of the plate, so that when the disc and top were screwed together by a screw passing through (s), the disc was prevented from rotating when brushed. The end of the wire (w) (fig. 3), connecting the disc with the electrode of the electrometer, was screwed in between the head of the screw and the disc.

To obtain quantitative results, it is necessary to be able to give the disc a constant rub. I found that a small camel's-hair brush forms a very convenient rubber. The hair is a sufficiently good insulator, not very difficult to discharge after a whisk across the metal, and it does not scratch the metal—a most important consideration. I always gave the disc a single whisk—never a plurality—for one reading. I drew the brush across the middle zone (z) (fig. 3), exerting as

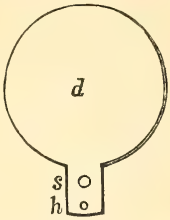


Fig.1.

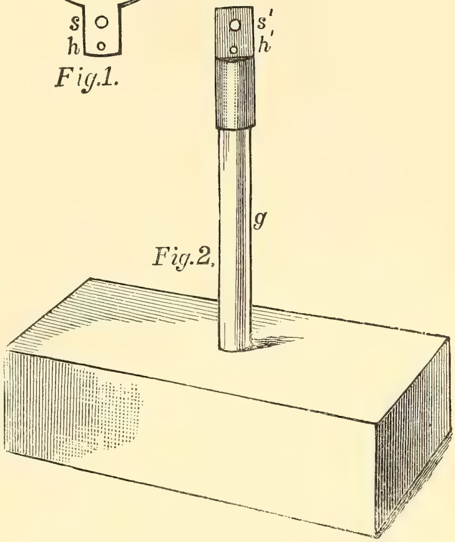


Fig.2.

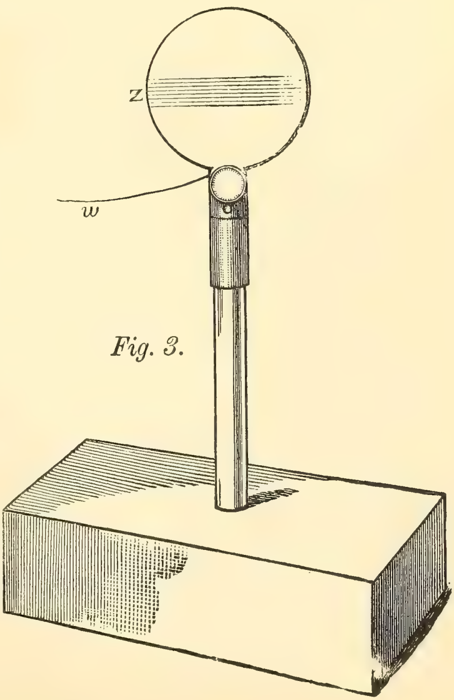


Fig. 3.

far as possible the same pressure each time, and moving with the same velocity. Variation in velocity produces very considerable variation in the amount of electricity produced, or at least left after the operation. It is also necessary that the brush be spread out to an equal extent in the successive whisks. I found that by first placing the brush in position at the side at a constant angle to the disc, and then moving it across with due regard to pressure and velocity, that a set of successive readings has very considerable constancy. For example, the following for copper, taken at random from my note-book :—

Whisk.	Reading.	Difference from Mean.
No. 1.	110	+ 2·5
2.	100	− 7·5
3.	110	+ 2·5
4.	90	−17·5
5.	125	+17·5
6.	110	+ 2·5
7.	90	− 7·5
8.	110	+ 2·5
9.	115	+ 7·5
10.	115	+ 7·5

Mean, 107·5

The differences are fairly alternate in sign, and the mean of the readings may with reason be assumed as giving the effect of the rub aimed at in the ten trials. However, I found later on that the readings tend to increase as the succession of whisks goes on.

It may be asked, Does the brush change in power after making a considerable number of whisks? De la Rive in his memoir cautions us when rubbing with a stick of wood to use a new stick each time, or else to scrape the surface used with a bit of glass. Were it necessary to use a new brush each time, then to make the thousand and half observations which I have made would be a matter of expense. When the brush is heated slightly before the fire, it produces a larger deflection than when it is not heated. For example, after I had finished the series of readings for copper, given above, and similar series for zinc, tin, iron, and lead, I held the brush

for a minute before a strong fire, and then took three readings. The deflections were—

195, 215, 220,

giving an average of 210, which is nearly double the previous average. Hair is known to be highly hygroscopic; the heating drives off the moisture, and the brush, when brought to the electrometer, is found to be electrified positively. Flannel, after being warmed before the fire, is also electrified positively. These facts seem to favour the idea that electricity is produced by evaporation. It is not advisable to have the brush very dry, for it is then more troublesome to take away the charge from it before using it a second time.

In the record of results appended (Table I.) I have entered all the average readings obtained. Each entry is the average generally of ten deflections, sometimes of fifteen and of five. The number of single observations made is upwards of one thousand. The course of the experiments breaks up into four series.

In the case of the first series I experimented with a disc of copper and a disc of zinc, each of which had one side highly polished. The two averages for zinc obtained on the 26th November are nearly equal to one another, and to the average of all the average readings. It is necessary to choose a standard number for one of the metals, and to compare the others with it; hence copper is always taken as 100. The electrometer was duly replenished each morning, and all the conditions were preserved constant as far as possible; but various circumstances caused the magnitude of the deflections to vary considerably from day to day. The first entry of 26th November was got by observing the first swing of the electrometer, the second by observing the permanent deflection. In all the subsequent observations it was the permanent deflection which was noted. One side of the copper disc was not so highly polished as the other; the rougher side gave an average of 123; the more polished taken subsequently gave an average of 126. I do not consider this comparison as conclusive; for I afterwards found that a disc of copper gave a decidedly larger deflection than a disc of brass copper-plated; and one of the differences between the two discs was, that the latter had a much smoother surface. Another expe-

TABLE I.—*Record of Mean Results.*

Series	Date.	Copper.	Zinc.	Lead.	Iron.	Tin.	Brass.	Gold.	Silver.	Nickel.	Platinum	Bismuth.	Antimony.	Aluminium.	Magnesium.	German Silver.
Series I.	Nov. 23	100	65													
	,, 26	,,	47													
	,, ,,	,,	44													
	,, 29	,,	45													
Series II.	Dec. 3	(cent) 100	...	...	...	...	...	123	71							
	,, ,,	(penny) 100	...	...	...	...	...	...	109							
	,, 4	...	...	...	...	...	...	193	100							
	,, 5	100	...	...	...	...	...	...	...	...	136					
Series III.	,, 6	,,	65	102	48	130	69									
	,, ,,	,,	51	80	38	102	54									
	,, 7	,,	50	41	45	121	55									
	,, ,,	,,	...	62												
	,, 12	,,	25	53	41	117										
	,, ,,	,,	54	115	91	180										
	,, 13	,,	24	60	72	118										
	,, 14	,,	27	45	53	84										
	,, ,,	,,	...	45												
	,, 17	,,	43	61	36	75										
	,, ,,	,,	43	53	61	103										
	,, 18	,,	48	48	72	89										
	,, 19	,,	36	39	62	81										
Series IV.	,, 20	,,	...	...	...	...	...	192	95	72						
	,, ,,	,,	...	...	.	...	...	136	90	56						
	,, 21	,,	...	...	...	...	...	158	83	48	...	23	37			
	,, 27	,,	...	...	...	...	...	210	132	48	...	17	23	37	49	32
	,, 28	,,	[42]	...	...	[143]	...	207	107	71	...	27	53	62	41	
Final Mean		100	45	62	56	126	59	181	102	59	136	22	38	50	45	32

riment was made with the copper disc with the view of ascertaining whether an increase of temperature had an effect upon the amount of electricity produced by the whisk. The disc was heated to such a temperature that it could not be held in the hand with any degree of comfort; the deflections were—

100, 100, 120, 85, 170, 170, 105, 115, 155, 165, 180, 145, 120, 180, 200,

giving an average of 140, compared with 126 before heating. When a brass disc was heated in a similar manner, the average deflection was increased in much the same proportion. It is not improbable that the effect is due to the heat of the disc increasing the insulation of the brush (see p. 428).

On the 29th November the surfaces of the discs were polished with a fine sand paper. The several observations were—

Copper, 215, 220, 210, 150, 167, 165, 140, 165, 165, 215, 145, 180, 215, 185, 140.

Zinc, 35, 70, 80, 70, 90, 40, 110, 75, 45, 110, 70, 85, 90, 65, 75, 110.

The average for the copper is 178; for the zinc 45, if the first reading is not taken into account and the last is, and 42 if the first is and the last is not. The smallness of the first deflection is to be attributed, I believe, to a few of the minute particles of zinc or of sand produced in the cleaning process still remaining on the surface of the metal. Many of the subsequent experiments were made with the view of clearing up this effect, and the still greater effect generally produced when zinc is polished with emery paper.

The second series of observations were made with coins and a platinum capsule, while discs of other metals were being prepared. A half-sovereign (11/12 fine gold), a sixpence (37/40 fine silver), and a cent (88 Cu to 12 Ni), are of nearly equal diameter, and therefore of nearly equal capacity. If the cent be taken as 100, the sovereign is 123, and the sixpence 71. The second comparison was obtained by taking a florin and a penny (95 Cu to 4 Sn and 1 Zn); the result obtained by supposing the bronze equivalent to copper gives a result for silver (109), which agrees well with the best strict comparison (107). The result of 4th December, gold to silver as 193 to

100, was obtained by comparing a sovereign and a shilling; it agrees well with the ratio obtained afterwards. The surfaces of the coins were cleaned with bath-brick and wiped against flannel; in no case were the readings anomalous at the beginning. The comparison obtained for platinum is only an approximation. It was obtained by comparing a small platinum capsule, kindly lent me by Mr H. R. Mill, with a florin and a penny. The true value is probably nearer to that for gold.

In the third series of observations I made many comparisons with discs of copper, zinc, lead, iron, tin, and brass. The reason why so many comparisons were made was to clear up an anomaly which appeared when the surfaces were polished with emery paper. In the case of the observations of 6th December, one side of each disc was rubbed with emery paper, and then wiped with a dry flannel cloth. The copper disc was first tried; it gave readings none of which differed greatly from the average, namely, 147. But the zinc disc when taken gave on the first whisk +110,* on the second +45; after a few whisks the deflection vanished, then became negative, and gave a series of ten readings agreeing closely with their average, 95. The iron disc also gave a positive deflection at first +80; it likewise changed after a slight brushing, and gave ten readings agreeing pretty well with their average, 71. When a fresh part of either of these discs was rubbed, the deflection became positive. In the case of the lead disc the deflection was considerably smaller than the average at the beginning. In the case of the copper and the tin discs there was no such marked irregularity; but the average of a series for copper taken at the end, 187, was greater than the average of the series taken at the beginning of the observations, 147. The values entered in the upper line for the 6th are obtained by giving copper its initial average, and those in the lower line by giving it the final average.

Next morning, 7th December, no emery paper was used; the surfaces were merely rubbed with a piece of white flannel which had been well dried. The copper disc gave regular negative deflections as before, but the zinc disc gave a positive deflection at first. After a few brushings across the middle zone of the disc, the deflection became negative, and remained about an average. The first read-

* When no sign is put before a number, the sign − is to be understood.

ing for tin was smaller than any of ten subsequent, and such was the case also with the brass; they were noted, but not included in the average. Two series were taken for lead, the former for the side which had been roughened by polishing, the latter for the side which had not been interfered with; in both cases the first whisk gave a nearly null deflection, but the deflection afterwards became pretty steady about an average.

To further elucidate the cause of this initial phenomenon, I rubbed each disc several times with a piece of flannel stretched over my forefinger. The electricity was not discharged after each rub, but was allowed to accumulate :—

Disc.	Electricity.
Lead (rougher side), . . .	positive.
Copper, ...	negative.
Zinc, ...	,,
Tin, ...	,,
Iron, ...	,,
Brass,	. negative, with trace of positive at first.

The lead disc was tried again, using the same side, and rubbing with what was noted to be a specially clean part of the flannel. It became negative at first, then positive after several rubs with considerable pressure. The same operation was repeated, and with the same result. The more polished side was then tried; it was negative at first, and greater pressure in rubbing was required to produce positive. Hence, the anomalous electricity produced on the lead is undoubtedly due to the fact that the rubbing with the flannel cloth abraded the lead (or the oxide of lead), as was indeed evident from an inspection of the cloth after the operation. And these trials also show why lead and bismuth and graphite were so prone to become positive under the friction to which they were subjected by De la Rive and the other experimenters. The ease with which these substances make a mark on paper shows that they can be easily abraded; and when the rubbing is so violent as to cause abrasion, anomaly may very well be expected.

The camel's-hair brush changes the electricity not from negative to positive, but from positive to negative. It certainly does not abrade the surface. Does the explanation of the anomaly con-

sist in this, that the brush sweeps away abraded particles which have been left by rubbing with emery paper and flannel cloth, or with flannel cloth alone, that so long as any of these particles are in its course the deflection is more or less altered in the positive direction; and that after they have all been swept off by a few whisks we get the true unimpaired reading? I believe that that is the proper explanation.

On 12th December the surfaces were prepared by rubbing with dry bath brick and flannel. Zinc, iron, and lead were positive at first; the zinc most, the iron next, and the lead least, and the zinc required the greatest amount of whisking to change it to negative.

In case of 13th December the discs were merely brushed with a large soft brush before beginning. The zinc was at first slightly positive. The readings were not so satisfactory as usual on account of imperfect insulation due to very moist weather.

On 14th December the discs were rubbed with warm flannel. Only the zinc and lead gave positive deflections, the former more persistently than the latter. The copper disc was then rubbed with sand paper, and the following series of observations taken, the first before the disc had been brushed in any way:—

	Repeated Brushing.
60	110
50	115
	115
	120
Mean 55	Mean 115

Repeated Brushing.	Repeated Brushing.
105	125
105	116
110	118
106	125
Mean 106	Mean 121

The brushing was done by the brush used to make the readings. The first brushing has much more effect than any of the subsequent ones; and this favours the idea that free particles of the metal are

removed by it. When the zinc disc was rubbed with sand paper and treated similarly, the following series of observations was obtained :—

	Repeated Brushing.	Repeated Brushing.
+10	+23	0
+28	+12	10
	+27	0
	+15	0
Mean +19	+19	2·5

The observations of 17th December, given in full in Table II., may be taken as illustrative of the other sets of observations. The morning was frosty, the stem insulated without being dried, the brush was heated slightly before beginning. The former series was taken with the discs as found; and the latter, after the discs had been polished with emery paper and cleaned with flannel. The order of entry is the order in which the observations were made. It will be observed that the initial and final readings for zinc in the first series are nearly equal, showing that the state of the brush was practically constant throughout. In the case of the second series, four readings were first taken, then the disc was whisked with the brush backwards and forwards across the middle zone about a dozen times, and then six more readings were taken. The order of the metals is the same, whether the former or latter mean of the second series is taken—zinc, lead, iron, copper, tin,—and this order agrees with that deduced from the entire collection of observations, excepting that lead is more negative than iron.

The comparisons entered for 18th December were obtained without rubbing the discs previously. The order is the same as the latter order of the previous days, excepting that tin comes out less than copper, which I believe to be erroneous. On the 19th the discs were previously rubbed with chamois leather. Zinc and lead were at first positive. On these two days an experiment was made with the zinc disc. On the former day it was rubbed with emery paper and chamois leather, and the mean of the first four readings was +111. By repeated whisking it was brought down to zero, and changed to negative. The disc was again rubbed with emery paper and chamois leather, tested once, and found to

TABLE II.—*Observations of 17th December.*

First Series.—Discs without being polished.

Zinc.	Copper.	Iron.	Tin.	Lead.
105	330	35	175	+25
100	238	45	160	38
103	256	82	160	70
112	345	80	190	Whisked
125	260	65	165	with brush.
107	245	70	170	160
127	280	70	150	155
105	213	95	190	170
125	265	65	140	220
115	210	90	155	138
				178
				115
				200
				140
				130
Mean 112·4	264·2	69·7	165·5	160·6

Tin again, whisked repeatedly with brush before beginning.	Iron again, whisked repeatedly with brush before beginning.	Zinc again.
185	80	110
225	78	125
210	90	110
210	90	148
180	120	127
175	98	132
195	105	95
170	105	100
215	90	115
205	95	120
Mean 197	95·1	118·4

Second Series.—Discs after being polished.

Zinc.	Copper.	Tin.	Iron.	Lead.
+190	150	195	50	0
+125	180	245	110	25
+ 85	187	195	88	40
+ 70	160	188	85	35
Mean +118	169	206	83	25
Whisked.	Whisked.	Whisked.	Whisked.	Whisked.
100	180	210	88	110
80	195	160	145	120
78	240	220	140	110
90	217	245	145	80
105	220	210	120	115
80	185	240	110	100
Mean 89	206	214	125	106

give a positive deflection about the magnitude of the above, and left untouched till next day. When tested next day it gave a reading about +52, and after considerable whisking the positive deflection vanished and changed to negative. The result of this experiment favours the idea that the positive electricity is due to the existence of minute particles on the surface of the disc.

On 20th December further experiments were made to elucidate the effect of rubbing with emery paper and with sand paper. The rubbing paper was attached to the end of a glass rod.

	Emery Paper.	Sand Paper.
Copper, . .	+ very slight.	+ more than with emery.
Tin, . . .	0	−
Iron, . . .	+ more than copper, less than zinc.	0
Zinc, . . .	+	0
Lead, . .	+ less than zinc.	+ more than with emery.

I scratched the surface of the zinc disc with emery paper; when the scratch was rubbed with the brush positive electricity was obtained, but after the scratches were rubbed a few times the electricity became negative. This experiment indicates with what care observations must be made in this subject in order to obtain definite results.

The fourth series of observations were taken up with gold, silver, nickel, bismuth, antimony, aluminium, magnesium, German silver. The first three are in the form of discs of brass electro-plated. The aluminium and magnesium are cut out of thin sheet metal, and are screwed on to a disc of brass. The electro-plates were on the 20th, 21st, and 27th compared with the disc of copper, but on the 28th with a similar electro-plate of copper. It was found that the copper electro-plate gave only two-thirds of the deflection given by the copper disc; the entries for the previous days have been corrected by multiplying by $\frac{3}{2}$, the other discs are compared with the disc of copper.

On 20th December the electro-plates were rubbed with clean chamois leather before beginning, and they were whisked a few

times with the brush before any readings were noted, as the deflections appeared too small. A new brush was used. Two series of observations were taken; in the former case the copper was observed before the electro-plates, in the latter after the electro-plates.

On 21st each disc was rubbed with chamois leather beforehand. The bismuth was null at the first whisk, the antimony was negative.

On 27th December an elaborate system of readings was taken. The entries in Table I. are deduced from the following four series of means :—

	1st Series, after being rubbed with chamois leather.	2nd Series, after brush was heated slightly before the fire.	3rd Series, after being rubbed with warm flannel.	4th Series, after being heated before the fire.
Copper (disc), .	101	309	...	319
Gold, . . .	79	228	192	212
Silver, . .	36·6	83	129	184
Nickel, . .	3	39	50	56
Antimony, . .	+38	...	70	...
Bismuth, . .	+20	56·5	+2	48
Aluminium, .	35·3	...	119	...
Magnesium, .	49·6	...	+77	...
German Silver, .	28	...	109	...

The electro-plates had been lying in a cold room since the 21st, and they were very moist when first taken up. This moisture on the surface probably explains why the ratio of silver to copper and of nickel to copper, changes so considerably. The other discs were brought from a warm room. I consider that the positive values entered are due to the existence of small particles of some kind on the metal.

The observations taken on the 28th are given in full in the accompanying table (Table III.). After the first five readings the disc was commonly whisked half a dozen times or so with the brush used. I have marked when this was done. It had the effect of increasing the reading. All the discs were brought from home, and a new brush was used. It will be observed that the mean for the copper electro-plate is less than for the copper disc; the result deduced from the different ratios is 2 to 3. In the second series only bismuth gave positive deflections, and these were soon changed to negative. Zinc was negative from the first, and repeated whisk-

ing by the brush did not alter the mean very much. The value obtained, 42, does not differ much from the final mean, 45. This result gives strong support to the explanation given in this paper of the occasional positive electricity produced in zinc and some other metals.

Table III.—*Observations of 28th December.*

First Series.—After being rubbed with warmed chamois leather.

Copper (disc).	Gold.	Copper (el.-pl.).	Silver.	Nickel.
105	128	60	70	48
105	130	70	68	44
105	145	80	75	48
128	180	75	80	45
138	170	70	85	44
Mean 116	151	71	76	46
		Whisked.	Whisked.	Whisked.
145	230	110	120	78
165	200	117	105	87
157	225	100	110	75
140	200	105	115	73
175	228	105	115	80
Mean 156	216	107	113	79

Second Series.—After being cleaned again.

Copper (disc), with emery and flannel.	Copper (el.-pl.), with warm flannel.	Tin, with emery and flannel.	Antimony by hand.
76	80	210	65
103	90	190	60
130	83	188	78
130	88	190	80
145	100	200	78
Mean 117	88	196	72
Whisked.	Whisked.	Whisked.	
200	105	210	Aluminium, chamois leather and hand.
180	108	170	
200	115	200	
190	104		
150	103	Mean 193	95
Mean 184	107	Reverse Side.	73
		240	78
		315	84
		240	90
		Mean 265	Mean 84

Table III.—*Second Series*—continued.

Bismuth, flannel and hand.	Magnesium, emery, flannel, hand.	Zinc, emery, flannel, hand.
+20	28	55
+46	45	54
+35	53	30
+32	40	50
+15	58	80
	70	
Mean +30	80	Mean 54
	76	
Whisked, gave negative electricity.		Whisked.
28	Mean 56	60
30		50
18		44
		30
0		Mean 46
+20		
		Whisked.
50		70
60		60
30		60
		50
Mean 36		
		Mean 60

On the 27th the following observations were taken (Table IV.). With flannel for the rubber only lead and bismuth were positive,

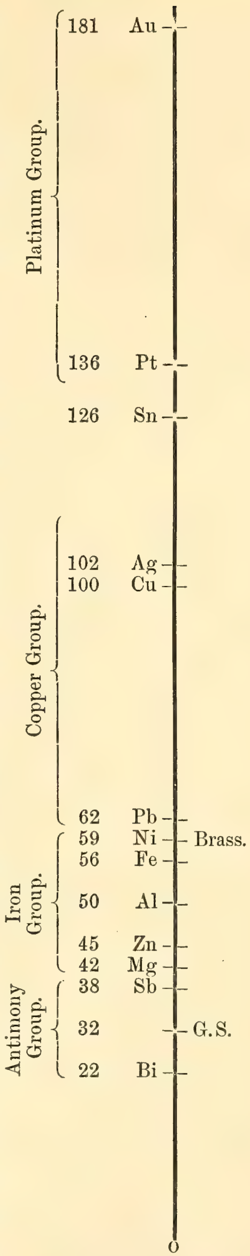
Table IV.

	Flannel.	Hand.	Sulphur.	Caoutchouc.	Sealing Wax.	State of Metal.
Gold, ...	–	–	+	–	–	No scratches.
Tin, ...	–	–	+	+	+	Wax and other.
Copper, ...	–	–	+	+	+	Wax.
Silver, ...	–	–	+	+	–	Few wax.
Lead, ...	+	–	+	+	+	Wax and other.
Brass, ...	–	–	+	+	–	Wax.
Iron, ...	–	–	+	+	+	Many, mostly wax.
Zinc, ...	–	–	+	+	+	Wax and other.
Nickel, ...	– or +	– (very small)	+	+	+	None.
Antimony, . . .	–	–	+	+	–	None.
Bismuth, . . .	+	+	+	+	+	Wax and other.
Aluminium, . . .	–	–	+	+	+	Wax and other.
Magnesium, . . .	–	–	+	+	+	Wax and other.
German Silver, .	–	–	+	+	–	None.

with the hand only bismuth. These are undoubtedly anomalies, caused, I believe, by the abrasion of the metal. The exceptional

result for gold, when caoutchouc was the rubber, is doubtless due to an error in entering the result. But with sealing wax as the rubber we have varying signs. When the electricity of the metal was negative, there was no red scratch (a very little in the case of silver) left on the metal; when the electricity of the metal was positive, there was a red scratch, excepting in the case of nickel. I conclude that the electricity of the metal is normally negative, but that when the wax is abraded it is changed to positive.

By taking the average of all the averages, we get the values in the bottom row of Table I.; they are exhibited graphically on the accompanying scale. The order of the metals here exhibited is not an arbitrary order; it agrees pretty well with the order in which the chemists arrange them, with respect to their affinity for oxygen. This was observed by Professor Tait at an early stage of the experiments. The metals of the iron group are found close together, and their order among themselves is also significant. The metals of the copper group are found together, but of these lead is at a considerable distance from the others; the entries for that metal, however, vary considerably. Platinum and gold are next one another; the value for the former is as yet only approximate. The chemist classes tin along with antimony and bismuth; the two latter are found to-



ELECTRO-FRICTIONAL SCALE.

gether and at the positive end of the scale, while tin is nearly at the negative end of the scale.

The results of Becquerel may be deduced from this scale, with the exception of the position of tin and of iron. He agrees in making antimony and bismuth positive to zinc.

For the sake of comparison, I exhibit the electro-frictional series, deduced from this scale alongside of three other series which we should expect to have an intimate resemblance.

TABLE V.

Electro-Frictional Series.	Electro-Chemical Series, by Berzelius.	Electro-Contact Series, by Hankel.	Electro-Contact Series in Air, by Ayrton and Perry.*
Gold.	Antimony.	Platinum.	Platinum.
Platinum.	Gold.	Silver.	Copper.
Tin.	Platinum.	Gold.	Brass.
Silver.	Silver.	Copper.	Iron.
Copper.	Copper.	Iron.	Tin.
Lead.	Bismuth.	Bismuth.	Lead.
Brass.	Tin.	Antimony.	Zinc.
Nickel.	Lead.	Lead.	
Iron.	Nickel.	Tin.	
Aluminium.	Iron.	Zinc.	
Zinc.	Zinc.	Aluminium.	
Magnesium.	Aluminium.		
Antimony.	Magnesium.		
Bismuth.			

It will be observed that the principal diversity consists in the positions of antimony, bismuth, and tin—all metals of the antimony group. As regards crystalline form, tin differs from the other metals comprised in the electro-frictional series; it belongs to the quadratic system. Silver, gold, copper, iron, lead, which are found together in the series, belong to the regular system of crystals; while antimony, bismuth, zinc, magnesium, which are also found together, belong to the rhombic system. The last four metals also agreed in exhibiting the greatest tendency to be positive at first.

BUSINESS.

Dr Francis T. Bond was balloted for, and declared duly elected a Fellow of the Society.

* *Trans. Roy. Soc.*, vol. clxxi. p. 34.

Monday, 21st January 1884.

ROBERT GRAY, Esq., Vice-President, in the Chair.

The following Communications were read:—

1. On Distant Vision. By E. E. Maddox, M.B., C.M. Communicated by Prof. Crum Brown.

I believe it is universally assumed by English physiologists that the zero of accommodation is naturally associated with parallel visual axes as in the "Primary Position" of Helmholtz, Listing, &c.*

It is self-evident that when even in actual life a body is viewed at infinite distance the visual axes must be parallel. It is also well known that the nervous connection between convergence and accommodation is a most delicate and susceptible one, and is none the less so naturally because it is capable of being overcome for a time by various conditions. It is therefore quite reasonable to suppose that when the ciliary muscle is at rest the converging mechanism should be so likewise; and to expect that the invariable association of the visual actions of a life-time should be impressed, if not at birth, as Porterfield suggested, "by an original, connate, and immutable law," at least by "dint of habit," upon the very constitution of the governing ganglia.

That this is not the case will be evident from the following experiment:—Let two small round holes be made through a piece of paper, nearly two and a half inches apart. Hold them horizontally about six inches before the face, and look through the left hole with the left eye at some very distant object. Four images now, of course, appear as shown in fig. 1. Each hole throws a direct image nearly upon the macula of its corresponding eye, and another image obliquely upon the outer part of the retina of the opposite eye. The appearance which results is represented in fig. 2. The two

* "In investigating the movements of the eyes, we take as a normal point of departure a position of the eyes which corresponds to a *minimum of innervation* of their muscles. In this position, which is called the *primary position*, the visual lines are directed straight in front, parallel to each other, and in the same horizontal plane."—*Landolt.*

direct images which fall nearly upon the retinal extremities of the visual axes are mentally referred close to the middle line in obedience to Hering's law (quoted and supported by Helmholtz), that points looked at in space are referred to a line drawn from the root of the nose to the junction of the visual lines. Thus the hole A may be referred to *c*, and the hole B to *d*. The two indirect images are referred to the outer side of the hole which gives rise to them. Thus the image of the left hole A, upon the retina of the right

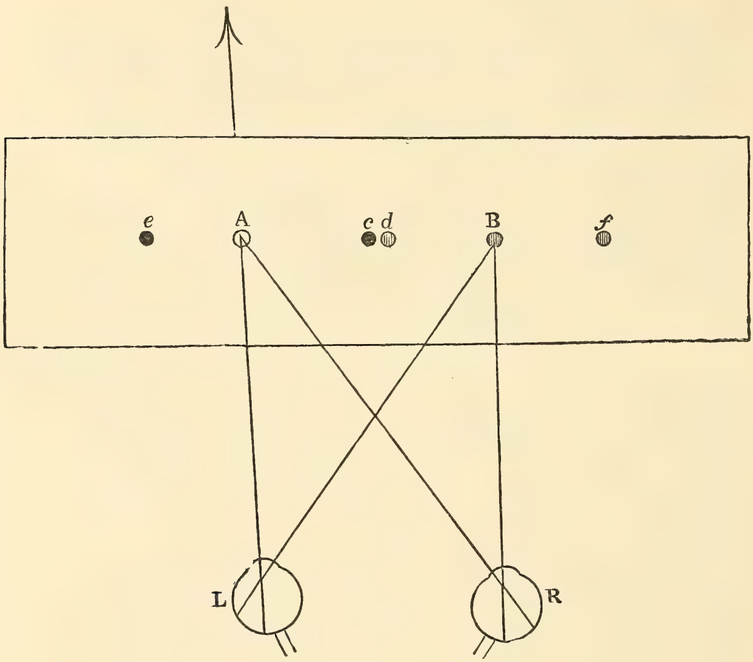


Fig. 1.

eye, is mentally referred to *e*, and the image of B to *f*. Neglecting for the present the lateral false images, it is easy to make the holes at such a distance that the two central false images *c* and *d* either coincide as in fig. 3, or appear in the same vertical line as in fig. 4, in which case a slight obliquity is given to the paper, though it remains in the same plane. Each hole is now exactly in the visual axis of its corresponding eye, and were these axes parallel, this would be a simple method of obtaining what Donders has called

the "interaxial distance." This, indeed, was my purpose in trying it. With parallel axes, moreover, the position of the false images should be unaffected by making the paper approach or recede, for accommodation is still negative, and the left eye looking at a distant object. In reality, however, if the distance of the paper be either increased or diminished, the two central false images separate in proportion. A piece of red glass held in front of the right hole

Fig. 2.

Fig. 3.

Fig. 4.

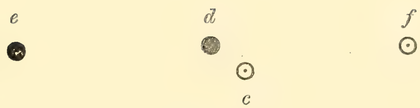


Fig. 5.

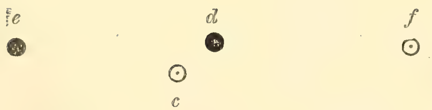


Fig. 6.

colours the right lateral image and one of the median ones, and shows that when the paper is made to recede, the red image travels to the right of the other, as in fig. 5, and when it is made to approach the red one travels to the left, as in fig. 6. From this it is clear that the visual axes are convergent. It may be objected that the

left eye only is looking at a distant object, and accommodation may not be entirely suspended in the right eye, in spite of the assertion of Donders that accommodative effort is always the same in each eye. This objection would be met by the fact, that when the two central images are in the same vertical line as in fig. 4, distant objects are seen in each which are really separated by an appreciable horizontal interval. It is difficult to represent natural objects diagrammatically in the holes; but if we let them be represented hypothetically by two vertical parallel lines at infinite distance, one red and the other blue, the red line would appear in one hole and the blue one in the other, as in fig. 7. In this *both* eyes

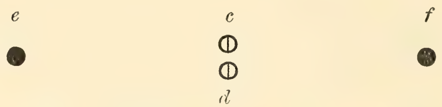


Fig. 7. Different objects are seen in *c* and *d*.

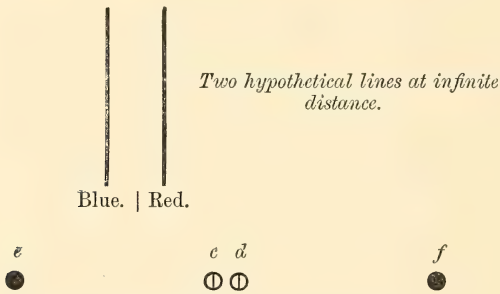


Fig. 8. The same object is seen in *c* and *d*.

are fixing distant objects. Again, when the images of the holes *appear* to be separated, as in fig. 8, the same object may be seen in each. The distance between the holes in this case represents nearly what would be the true interaxial distance when the axes are parallel (fig. 9). It is even possible for the two holes to continue separate for a little time when made exactly level, though usually they rush together without much delay. The simple experiment, with modification, is also available to determine the obliquity of the intercentral line, and the slight obliquities of the respective meridians of the two retinæ with the eyes at rest. For this purpose I make the holes through a piece of cardboard,

and fix a small spirit-level parallel to the line which joins them. The results of these experiments I must defer. It remains to

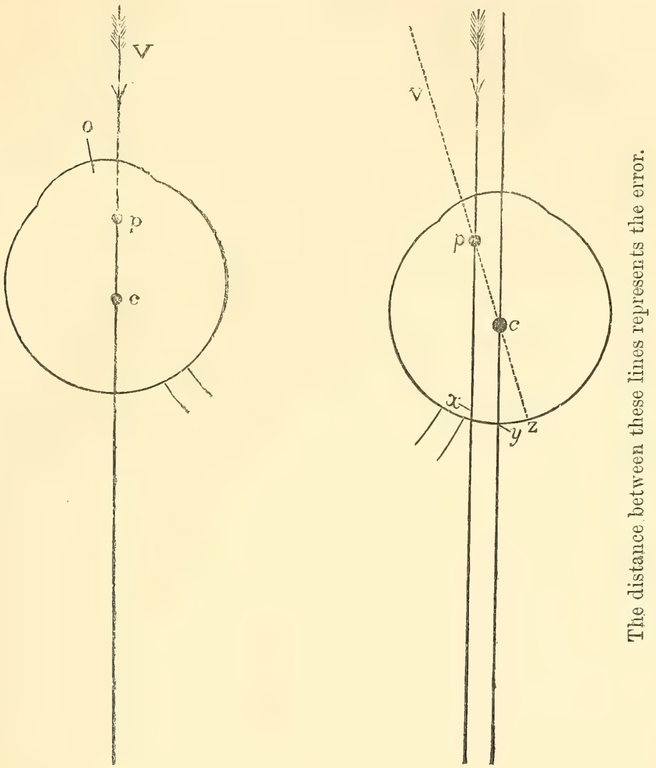


Fig. 9.

Position of two eyes when looking at the two holes, as in fig. 8 (exaggerated). V = visual axis of each eye. The left eye is looking direct at the left hole, but the right is somewhat convergent, so the image falls on x instead of on z, and is referred in consequence outwards.

Centre of Rotation, *c*. 1·77 mm. behind centre of optic axis (Donders).

Principal optical centre *p*.

The optic axis "*o*" (left eye) is seen not to coincide with the visual axis V.

estimate the exact degree of convergence which is naturally associated with negative accommodation.

To this end I have made use of a kind of camera devised for another purpose, and find with my own eyes that convergence

occurs to 1°, so that while accommodated for *infinity*, the eyes direct their *visual axes* to a point nearly 12 feet distant. Suppose, now, the eyes are *accommodated* for an object at the distance of 12 feet. Surely now the accommodation and convergence will coincide! No; the right eye rolls inwards another 40′. The optic angle is therefore 1° 40′. It is easy to calculate trigonometrically, knowing my own intercentral distance, that the visual axes must now intersect rather more than 7 feet from the eyes, while accommodation takes place for nearly 12 feet (11 feet 8).

The slightest increase of accommodation is associated with a sympathetic advance of convergence, and there is a decreasing interval between the two. The excess of convergence over accommodation diminishes as the object of view approaches till a certain point, when they both coincide. This point in my own case* is 56 inches distant. As the visual object approaches still nearer, convergence fails to keep pace with accommodation. With each increment of accommodation throughout there is a corresponding increment of convergence, but a smaller one. It is like a long-legged and a short-legged competitor in a race, in which both are bound to keep step, the short-legged having a start, but the long-legged winning in the end. Being somewhat hypermetropic, my convergence would be expected to exceed my accommodation when the latter is negative, but strangely I have found the excess greater in most normal eyes I have tried than in my case, and to vary from 4° to ½°. I have not been able to experiment on many, but I have found it quite as much in one or two myopic patients.

It raises the question, What is the position of rest of the eyes which they would assume in sleep?

I think it may be accepted as extremely probable that it is the *natural condition* of brain centres, at least those connected with the eye, to evolve some nerve energy, even in sleep. It is impossible for most people to relax their ciliary muscle completely without a distant object to look at, and even the faculty claimed by some oculists to be acquired by training, is received by their brethren with much incredulity. Evidently the degree of convergence, though it does not coincide with accommodation, is closely affected

* I am unable to continue experiments on myself.

by the latter. It may altogether be laid aside that the primary position of the eyes is that of rest. Landolt says—"It is impossible for any one who has not practised to that end to give his eyes a direction absolutely parallel, especially in strabismus." How he arrived at this result I do not know, but probably with the ingenious apparatus of Javal, which requires a candle near the patient's face and a dark room.

Convergence without any definite point of view, therefore, must probably be considerable. Even the centre for the contraction of the pupil by light, which is regarded as a typical example of a reflex instead of a tonic ganglion during waking hours, is not improbably a tonic one naturally, for the pupil is semi-contracted during sleep, and dilates the moment a person wakes up. Whenever a distant object is viewed, impulses must ascend from the retina to inhibit reflexly the ciliary muscle, for it has no antagonist. It is just as easy to extend the process to the centre for the contraction of the iris, and suppose that the activity of some other centre exerts, during waking hours, an inhibition over the tonic moiety of nervous energy for the sphincter pupilli. This indeed might throw light upon the Argyll Robertson symptom of locomotorataxia and spinal myosis in general. It is impossible at present to decide, but I am inclined to believe that the position of rest for each person is that point of space for which accommodation and convergence are equal. Opinions, however, will probably vary between this point and others at a greater distance, but none will entertain parallelism.

These facts increase the difficulty of ascertaining the exact interaxial distance between the two eyes; indeed, the name would be better changed to intercentral distance, as I have taken the liberty of doing in this paper. A glance at fig. 8 will show that the conditions would not be altered in the least, if the holes were drawn out into two parallel tubes, since the object is at practically infinite distance. If a screw were adapted to these tubes for their mutual approximation, or the reverse, they would resemble the visuometer for determining the interaxial distance.

It is conceivable that many subjects might aver that they saw the same object through both tubes, when in reality the objects were not completely fused. The error introduced is due to the fact

that the principal optical centre of the dioptric apparatus is more than 7 mm. anterior to the centre of rotation. In the following table I have estimated the degree of error for each $\frac{1}{2}°$ of convergence with distant vision. It is seen to be very trifling, and to reach half a millimetre only with 4° of convergence in emmetropia. In myopia the error would be greater.

0° 30′	·06465 mm.	3° 30′	·4221 mm.
1°	·12635 mm.	4°	·5050 mm.
1° 30′	·1895 mm.	4° 30′	·568 mm.
2°	·2527 mm.	5°	·631 mm.
2° 30′	·3158 mm.	7° 56′	1 mm.
3°	·3789 mm.		

The error is avoided by the practice of shutting each eye in turn. It may be suggested that the eyes tend to take the position in which their optic axes are parallel, rather than their visual axes, but this would not account for the convergence of myopes in which the two axes coincide; and in my own case, convergence in spite of hypermetropia is almost certainly less than the angle between the visual axes by two or three degrees at least. The two conditions so far seem to be quite independent.

2. On the Formation of Small Clear Spaces in Dusty Air. By Mr John Aitken.

(*Abstract.*)

In the introduction a few remarks are made on the growing interest in everything connected with dust, whether it be the organic germs floating in the air, or the inorganic particles that pollute our atmosphere. Professor Tyndall's observations on the dark plane seen over a hot wire* are referred to, Lord Rayleigh's recent discovery of the dark plane formed under a cold body† is described, and attention called to Dr Lodge's experiments, detailed in a letter to *Nature*, vol. xxviii. p. 297.

* *Essays on the Floating Matter in the Air*, p. 5, Longmans, Green, & C 1831.

† *Nature*, vol. xxviii. p. 139

The experiments described in this paper were made in a small dust-box, blackened inside, glazed in front, and provided with a window at one side. For illumination two jets of gas enclosed in a dark lantern were used. The light entered the dust-box by the side window, and could be condensed on any part of the inside of the box, by means of two lenses fixed in a short tube, and loosely attached to the front of the lantern. Magnifying glasses of different powers were used for observation. The dusts experimented on were made, some of hydrochloric acid and ammonia; some by burning sulphur and adding ammonia; others by burning paper, magnesium, or sodium. Calcined magnesia and lime were also used, as well as ground charcoal. These three last substances were stirred up by means of a jet of air.

For testing the effects of slight differences of temperature, tubes in some form or other were generally used. These tubes were closed at the front, projected through the back of the dust-box, and were brought close to the glass front, for observation under strong magnifying power. The tubes were heated or cooled by circulating water through them in a small tube passing through their interior.

Suppose the experiments to be begun by introducing a round tube into its place in the dust-box, and filling the box with any dust, everything being then left for some time, so that all the apparatus may acquire the same temperature. If the light be now allowed to fall on the box, and be quickly brought to a focus on the tube, it will be found that the dust is in close contact with it, on the top and sides, but *underneath* a clear space will be observed; close examination will show that the particles are falling on the upper surface of the tube, and coming into contact with it, while underneath a clear space is formed by the particles falling away from it. If the tube is now slightly cooled, a downward current is formed, and the currents of dustless air from below the tube meet under it, and form a dark plane in the centre of the descending current. It is shown that gravitation can, under favourable conditions, produce this separation of the dust quickly enough to keep up a constant supply of dustless air. No increase of effect is produced by a lower temperature. A temperature of $-10°$ C. makes the dark plane

thinner, because it increases the rate of the descending current, and carries away the purified air more quickly.

A form of apparatus was arranged to get rid of this separating effect of gravitation. It consisted of an extremely thin and flat piece of metal. This test-surface was placed *vertically* in the dust-box. The air in passing over this piece of metal did not take up a horizontal movement at any part of its passage. The result was that even with a temperature $-10°$ C. the dust kept close to its surface, and no dark plane was formed in the descending current. The dark plane in the cold descending current seems, therefore, not to be an effect of temperature, but is the result of the action of gravitation on the particles under the body. A dark plane was, however, observed when working with this flat surface, when cooled; but it was not formed in dusty, but in foggy air, and was found to be due to the evaporation of the fog particles when they approached the cold surface.

If a very little heat, instead of cold, as in the previous experiment, is applied to the round tube, then the dark space under the tube rises and encircles the tube, and the two currents of clear air unite over the tube, and form the dark plane in the upward current. But in addition to this, heat has been found to exert a repelling effect on the dust. This was proved by putting the thin vertical test-surface in the dust-box, and heating it; when it was found that the dust was repelled from its surface, and a dark plane formed in the ascending current; neither of which effects was obtained with cold. The dust begins to be repelled with the slightest rise of temperature, and the dark space in front of the test-surface becomes thicker as the temperature rises. An experiment is then described in which the dust particles in the air flowing up between two parallel glass plates is caused to pass from side to side of the channel by the repelling action of heat at different points.

For testing the effects of higher temperatures a platinum wire heated by means of a battery was used. The platinum wire was bent into a U-shape, the two legs being brought close together. This wire was fixed in the dust-box with the bend to the front, and the legs in the same horizontal plane, the two copper wires to which it was attached being carried backwards and out of the box.

By this arrangement a clear view was obtained all round the wire, and other advantages secured. Experimenting with this apparatus, it was found that different kinds of dusts had different sized dark planes. With magnesia and other indestructible dusts, it was very thin; with the sulphate dust, it was much thicker; and with the sal-ammoniac dust, thicker still. So thick was it with the two latter kinds of dust, that the dark planes over the two legs expanded and formed one plane. As the particles could be seen streaming into the dark space under the wires, it was obvious that these large dark planes were not caused by repulsion, but by the evaporation or by the disintegration of the dust particles. When making the experiment in a mixture of different kinds of dusts, the hot wire was surrounded by a series of zones of different brightness, and having sharp outlines. The size of the different zones was determined by the temperature necessary to evaporate the different kinds of dust present, and outside these zones was another caused by the evaporation of the water from the particles.

The conclusions arrived at from these experiments are, that the downward dark plane is produced by the separating action of gravitation, in the space under the cold body, and that the upward dark plane is produced—1st, by the separating action of gravitation; 2nd, by the repulsion due to heat; 3rd, by evaporation; and 4th, by disintegration.

The effect of centrifugal force is considered. It is pointed out that as the air in its passage over a body such as a tube, curves as much in one direction as it does in another, therefore any centrifugal effect produced in the one part will be reversed in the other. An experiment is described in which an air current is caused to curve through 180 degrees in its passage round the edge of a thin plate, and without any curving in the opposite direction, but no decided centrifugal action could be detected.

The motions of the dust particles produced by the repulsion of the hot surface suggested that electricity might play some part in these phenomena. Experiments were made to test this: the hot body was insulated, and connected with an electroscope, but no electrical disturbance was observed, nor could any electrification be got from the dust and hot air streaming up from the hot wires. The effects

of electrification were studied by insulating and charging the hot surface. The effect was found to be the opposite of the heat effect. If the potential is slight and the temperature high, the heat is able to keep the dust off the surface of the body, and the dark plane distinct; but if the temperature falls, or the potential is increased, a point is reached when the electrical attraction overcomes the heat effect, and the dust particles break in upon and destroy the dark space.

It was observed that after the dust particles were electrified they tended to deposit themselves on any surface near them, and experiments were made to determine the best conditions for purifying air in this manner. It was found to be best done by causing as rapid a discharge of electricity as possible, by means of points, surfaces being placed near them to increase the electrification of the dust, and to augment the rate of the currents of air which were driven from the points. These surfaces became places on which the dust deposited itself before losing its charge. A large flask was found to be rapidly cleared of a cloud of dust by means of a point, the dust being almost entirely deposited on the inside surface of the flask. If the end of the conductor in the flask terminated in a sphere, but little effect was produced. Electricity has also been found capable of depositing the very fine dust of the atmosphere. The air in a large flask was purified much more quickly by means of the electric discharge than it could have been by means of an air-pump and cotton-wool filter.

It is shown that a wet and hot surface repels dust much more powerfully than a hot dry one. From this it is concluded that the heat and moisture in our lungs exert a protecting influence on the surfaces of the bronchial tubes, and tend to keep the dust in the air, which is ebbing and flowing through them, from coming into contact with their surfaces. This was illustrated by placing a hot and wet surface in a current of dense smoke, where it remained some time without receiving a speck of soot, while a similar surface, but cold, was blackened with the smoke. It is pointed out, that on account of the irregularities on the surface of the tubes and of the more violent movements of the air in the lungs, and on account of curves and projecting edges, the protection in the lungs

is not perfect. Still it is thought that this repelling action at these surfaces must have some influence, and it seems possible it may explain some climatic effects, as it is evident that the lungs will be much better protected in such places as Davos Platz, where the air is cold and dry, and the repelling forces at a maximum, than at places like Madeira, where the air is warm and moist, and these forces are at a minimum. This point can, however, only be determined satisfactorily by anatomical examinations of lungs which have lived under the different conditions.

In the experiments it was observed that dust not only tended to move away from hot surfaces, but also that it was attracted by cold ones, and attached itself to them. To study this effect, glass plates were put in different positions near the hot platinum wire. Very beautiful impressions of the dark plane can be obtained by placing a piece of glass vertically and transversely over the hot wire. The hot air in flowing over the glass deposits its dust on the surface of the plate, leaving a clear line in the middle, indicating where the dustless air of the dark plane had passed. In this way the dust is trapped on the glass to which it adheres with some firmness, and not only the impressions, but the dark planes themselves, may thus be preserved.*

Other experiments, to study the repulsion and attraction of hot and cold surfaces, were made by placing glass plates on both sides of the hot wire. An interesting result was obtained when the plates were about 1 mm. apart. Using magnesia powder, the particles could be seen rising in the current and approaching the hot wire; they were then observed to be violently repelled towards the cold surfaces, to which they adhered. If there was sufficient difference of temperature, not a single particle of dust was carried by the current past the hot wire.

A thermic filter is then described. In this filter the air is passed through the space formed between two concentric tubes. One tube is kept cold by a stream of water, and the other heated by means of steam or a flame. This instrument was shown in action. One end

* Specimens of these trapped dark planes were shown at the meeting. Some of them made of white powder deposited on blackened glass, others of charcoal deposited on opal glass.

of the filter was connected with a glass flask, in which the condition of the air was tested. So long as the difference of temperature was kept up, and the current not too rapid, the air passing through the apparatus showed no signs of producing cloudy condensation on the pressure being reduced, showing that the filter had trapped all, even the invisible dust particles.

Some experiments on the effect of diffusion on the distribution of dust at the surface of a diaphragm are described. Where carbonic acid diffuses into a space, the dust comes close to the diffusing surface; but if hydrogen is the diffusing gas, a clear space is formed in front of the diaphragm.

An explanation is then offered of the repulsion of dust by hot surfaces, and its attraction by cold ones. It seemed possible that the dust might be repelled in the same way as the vanes of a Crooke's radiometer, by a radiation effect. That this is not the true explanation was, however, proved by placing in the dust-box a polished silver flat test-surface, one half of which was coated with lamp black, when it was found that the dark space in front of the lamp black was no thicker than that in front of the polished metal. It is thought that the repulsion is due to the diffusion of the hot and cold air molecules. The hot surface repels, because the outward diffusing molecules are hot, and have greater kinetic energy than the inward moving ones; and as the side of the dust particle next the hot surface is bombarded by a larger number of hot molecules than the other side, it is driven away from the hot surface. The attraction of a cold surface is explained by the less kinetic energy of the outward than of the inward diffusing molecules. Some experiments are referred to, to show that the rate at which gas molecules diffuse indicate that this diffusion effect is sufficient to account for the repulsion and attraction of the dust.

If the explanation here given is correct, then the dust is repelled in the same way as the vanes of a radiometer when placed in front of a surface fixed inside the radiometer bulb, and hotter than the residual gas,—the principal part of the energy producing the motion being transferred from the hot surface to the repelled surface by the kinetic energy of the molecules, and not by radiation.

In illustration of the tendency of dust to move from hot, and to

deposit itself on cold surfaces, the following experiments were made. Two mirrors, one hot the other cold, fixed face to face and at a distance of two or three millimetres from each other, were placed in a vessel filled with a dense cloud of magnesia, made by burning magnesium wire. After a short time the mirrors were taken out and examined. The hot one was quite clean, while the cold one was white with magnesia dust. In another experiment a cold metal rod was dipped into some hot magnesia powder; when taken out it had a club-shaped mass of magnesia adhering to its end, while a hot rod attracted none.

This tendency of dust to leave hot surfaces and attach itself to cold ones, explains a number of familiar things, among others it tells us why the walls and furniture of a stove-heated room are always dirtier than those of a fire-warmed one. In the one case the air is warmer than the surfaces, and in the other the surfaces are warmer than the air. This effect of temperature is even necessary to explain why so much soot collects in a chimney. It explains something of the peculiar liquid-like movements of hot powders, and perhaps something of the spheroidal condition.

For practical application, it is suggested that this effect of temperature might be made available in many chemical works for the condensation of fumes, and that it might also be used for trapping soot in chimneys. A small trap of this kind was shown. It consisted of a tall metal tube or chimney, surrounded by another tube slightly larger. The products of combustion are taken up the centre tube, and down the intervening space. The heat of the gases is thus made to do its own filtering. This apparatus being placed over a smoky lamp, it trapped out most of the soot, and deposited it in the inside of the outer tube. This arrangement of apparatus is too delicate and troublesome for general use, and it is suggested that as by simply cooling gases in presence of plenty of surface, much of its dust is deposited, it might be possible and advantageous under certain conditions to purify air by heating and cooling it a number of times, which could be done at a small expense by means of regenerators.

Experiments were also made by discharging electricity into the smoke in a chimney. This also produced a marked diminution in

the blackness of the escaping smoke. The supply of electricity of sufficiently high potential is, however, a difficulty for the present.

3. The Remarkable Sunsets. By Mr John Aitken.

The very remarkable and beautiful sunsets which have been so frequent of late, in which the sky has been lit up with a wondrous wealth of colouring, and with a splendour more than earthly, has given rise to much interest and speculation as to the cause of the brilliant colouring. According to one explanation, the effect is produced by the light becoming coloured in its passage through the atmosphere by an excess of water vapour, or other absorbing medium, at present in the air. The other explanation is, that the effects are the result of a superabundance of atmospheric dust, probably due to the late eruptions of Krakatoa and other volcanic mountains.

There seems to be a possibility of determining by observations which of these theories is the more probable. In all the descriptions of the sunsets the point which is most generally remarked on is the immense wealth of the various shades and tints of red. Now, if dust is the cause of these glowing sunset colours, then there must be somewhere a display of the colours complementary to the reds; because the dust acts, not by the selective absorption, and destruction of the colours, but by a selective dispersion of them. The very small particles of dust in the atmosphere stop the direct course of the rays and reflect them in all directions; but the dust particles are so very small, especially in the upper regions, that they are only capable of stopping, and reflecting, or scattering the rays of the blue end of the spectrum, while the red rays pass on unchecked. There therefore ought to be somewhere in the sky a display of the colours of the blue end of the spectrum. From the observations I have been able to make since this suggestion presented itself, I find that the display of blue and green colours is quite as prominent a feature of the late sunsets as the reds.

Overhead the display of blue is fuller than I have ever seen it before; and as the sun passes below the horizon, and the lower stratum of air with its larger particles, which reflect white light,

cease to be illuminated, the depth and fulness of the blue increases in a very marked degree. While the sky is deep blue overhead it will be observed that lower down the blue changes to blue-green, and in some cases to green, the wonderful greenness sometimes seen in a clear space in the sky being occasionally intensified by contrast with a rose-coloured cloud or haze alongside of it.

These considerations seem to point to dust as the cause of the glowing colours of our late sunsets, as none of the colours are destroyed, but are simply sifted out and assorted, and the sunset colours seem to be produced in the following way: When we look into the clear blue sky overhead, we see the light selectively reflected from the small particles capable of scattering only the colours of short wave-lengths, and we see only blue. If in the evening we gradually lower our gaze, and look into the clear sky in any direction not towards the sun, we will then see that the blue gradually changes to blue-green, and sometimes even to green, and lower down it passes into white or rose-colour near the horizon, according to the circumstances. This green would seem to be produced in the following way: Suppose we are looking northwards, then the light which enters our atmosphere from the west has, before it arrives at the part of the sky into which we are looking, had much of its blue thrown out by reflection, and is therefore deficient in blue light; and the particles at that elevation are not large enough to reflect the red, so only green is reflected by the sky, and the red passes on. When we look overhead, we also look through this green stratum, so to speak, but the green is overpowered by the greater brilliancy of the blue. And, further, when looking upwards at only a slight angle, we see the light reflected from a far greater amount of the green stratum than when looking through it towards the zenith.

The fine particles of dust having thus scattered the blue and the green rays, only the red rays are allowed to pass on, and we see them reflected on the clouds far to the east of us, as well as to the south and north. Some of the most beautiful and delicate rose tints are formed by the air cooling and depositing its moisture on the dust, increasing the size of the particles till they are able to stop and reflect the rays of the red end of the spectrum, when the haze glows with a strange aurora-like light.

Another peculiar feature of these sunsets is the very remarkable amount of after-glow which has sometimes been observed. So brilliant is this after-light that to many it has seemed as if the light had returned and increased in brilliancy. This impression is, however, only subjective. If we watch the moon, it will be seen to become more and more brilliant, as the colour phenomena change, which would not be the case if the after-glow increased the light. The apparent increase seems to be due to the sensitiveness of the eye becoming restored, after being fatigued by the bright light of day, and part of the apparent increased brightness is due to the increased sensitiveness of the eye, and part is due to the illumination becoming coloured. These remarks are, of course, altogether apart from the wonderful increase of twilight lately enjoyed, which has lengthened the day by nearly an hour, and refer only to the apparent increase and return of the light.

The increased amount of red light which fell on the earth at and after sunset produced some very remarkable changes in the appearance of surrounding objects, causing all red or reddish-coloured objects to glow with a strange brightness, and destroyed the relation of the colours of the different objects to which we are accustomed. Dead beech leaves, for instance, which under ordinary conditions of light are not conspicuous, shone out brightly. But perhaps the most remarkable effect was observed when looking down on a town. Most of the houses were bathed in a uniform grey light; but all the tiled roofs shone out brilliantly, and looked very much as if they had just been painted with vermilion.

Monday, 4th February 1884.

THE RIGHT HON. LORD MONCREIFF, President, in the Chair.

1. The President delivered the following Address, giving a Review of the Hundred Years' History of the Society.

At the close of our last Session, I undertook to call the attention of the Fellows at the commencement of the present to the history of the Royal Society, taking as my theme the completion of its hundredth anniversary. Circumstances have accidentally delayed for a month or two the fulfilment of that engagement; but I now proceed, to the best of my power, to discharge it. It is a very wide theme, and it will at once occur to you that a review of the topics which have engaged the attention of the Society during that period, rightly performed, would be equally beyond my ability and your patience. I should have to speak an encyclopædia, in many volumes. I can, however, but attempt some desultory and fragmentary reflections, which may not be devoid of interest, on "the Foundation and the Founders of the Royal Society of Edinburgh," as they appear to us in retrospect through a vista of a hundred years.

There is no doubt now of our right to claim our centenarian honours. The Charter which we hold is dated on the 29th of March 1783. Several preliminary meetings were held for the election of office-bearers and the enactment of bye-laws, but the first meeting for the transaction of business was held on the 8th of December 1783. So that, had I been able to accomplish my task as I had intended, on the 4th of December 1883, I should have invited your attention to the proposed review, as nearly as might be, on the completion of a century of operative life on the part of the Royal Society.

I think we may look back on that long history with pride, with pleasure, and with profit. The attainment of this centenarian milestone in the life of man, or of nations, or of institutions, always brings with it an element of sentiment—a suggestion both of per-

manence and of change, which surrounds it with interest. It points to a commencement which probably no survivor recollects, and even in periods the least eventful, its long roll of expectations, efforts, and vicissitudes cannot be regarded without a share of emotion. But the century along which I invite you to look back to-night is so crowded with events in the political and social history of the world, that its commencement shades obscurely away into the past. Since that day in dim December, when our great predecessors first gathered together, under the shadow of their new Charter, all that was greatest and brightest in Scottish intellect at that time, what a marvellous wave of change has swept over the civilised world. The echoes of 1783 come to us as from the distant past, and range with the historic, not with the present. We think of the *Mirror* and the *Lounger*, rather as the contemporaries of the *Spectator* and the *Tatler*, than of ourselves, as though they had been the inhabitants of a different sphere from that in which we find ourselves to-day.

Such is the instinctive feeling which first arises in the mind when we try to span in thought the interval between then and now; and so I felt when I began my preparation for my duty to-night. I have in the course of it been living with the great men of former days, as I find their thoughts recorded in our annals. I have gone over our *Transactions* for the first fifty years of the existence of the Society, and have risen from my task deeply impressed by the wealth of cultivated ability which that repertory contains. I mean to ask you to-night to accompany me in rather a rapid journey over that period, along with some of the best travelling companions which Scotland ever saw. As I became familiar with details, and the actual personality of the men, I found the apparent distance perceptibly diminish, and began to think the century not so wide a chasm after all. This impression was heightened by finding, when I took my leave of our office-bearers at the comparatively modern half-way house of 1830, that three of them, at least, had accompanied me all the way. They were Henry Mackenzie, Baron Hume, and Sir William Miller of Glenlee.

Long or short, however, as it may seem to us in reflection, the century has witnessed signal changes, and many momentous events have been crowded into it. Many stormy days and nights must have

been witnessed by our founders. The Fellows of the Royal Society, no doubt, in its philosophic retreat, know nothing of politics—

> "Quid Tiridatem terreat unice
> Securi."

Nevertheless, since its meetings commenced, the changes on the world's chess-board have been numberless, and there is something impressive, if perhaps almost incongruous, in finding the Royal Society meeting quietly month after month in those first days of palpitation and alarm, as if utterly unconscious of the tempest which was raging without. The end of their first decade brought them to the deepest horrors of the first French Revolution. The end of the second, in 1803, saw the whole country armed to the teeth on the rupture of the Peace of Amiens. At the end of the third, Europe, after ten years of warfare and bloodshed, had not reached, although it approached, the crisis of Waterloo. Yet we could not have discovered from these records of learning what startling events were passing outside, while our forefathers discussed a geometrical problem, or pondered and disputed over the topography of the Troad.

Yet, regarding this long interval from the watch-tower of the Royal Society, I can trace within the century a revolution more wonderful and more extensive than monarchies, or empires, or republics can display. Since this Society held its first meeting, how great to the community has been the fruit gathered from those branches of knowledge which it was incorporated to prosecute! During that interval, what has science not done for human comfort and happiness? What interest so great, what dwelling so humble, as not to have felt its beneficent influence? Since the invention of the art of printing, no such advance in material comfort, prosperity, and intellgence has ever been made within a similar period as this century has witnessed. Its triumphs have not been confined to the more abstruse fields of thought and study, but have come straight to the world of everyday life. I need not go over the familiar catalogue; but one homely illustration meets me on the threshold of the opening night; and homely things go deep into the foundations of human life. I picture to myself our founders wending their way to the College Library, through close and wynd, in mid-winter 1783,

while flickering oil-lamps made the darkness visible without, and a detestable tallow candle made the student miserable within doors. Those who cannot recollect the universal reign of tallow candles and their snuffers cannot appreciate how much the sum of human enjoyment has been enhanced, and the tranquillity of human temper increased, by the transmutation—partial, we must admit—of darkness into light. There has been, I believe, no more potent agent in humanising the denizens of our large cities than the flood of light which chemical science has in our day poured into their recesses. The ingenious author of the diverting volume on the *Miseries of Human Life*, published, I think, about 1812 or 1814, was quite right in uttering one of his deepest groans over the illuminating horrors of that age of darkness. It does not detract from the picture that, great as have been the triumphs of gas light, it is said even now to totter on its throne, and prophets tell us that before the end of the century which we now begin, it will probably have followed the tallow candles into the same unlamented obscurity. Prophets are not agreed about this; but even should this be so, history will carry to its credit the vast amount of public utility, and the many hours of useful employment or comfort in the factory, the study, or the sick room, which this simple application of chemical science gained in its day for the nineteenth century.

But the dispersion of material darkness is but a slender illustration of the triumphs of scientific discovery. Time and space are no longer the tyrants they were in 1783. I rather think that when our founders first met, they could hardly hope to hear by post from London under ten days, as Palmer's mail coaches had not begun to run until 1789. It would be an interesting inquiry, if my limits permitted, to trace the moral and social effects of the change from the days when a London letter took even three days to reach Edinburgh, and cost 13½d Lord Cockburn lamented over the prospect of London being within fifteen hours of Edinburgh, as endangering the characteristics of our social community. His sagacity was not altogether at fault, but even that time has been reduced by a third, and I rather think we and the world are all the better of the change. But although larger victories were in store for the century, they came slowly. Both Boulton and James Watt were original members of the Royal Society, but it was more than thirty years before

steam navigation became general, and more than fifty before the first passenger railway train ran in Scotland. No doubt, in 1791, Erasmus Darwin, in his "Botanic Garden," a poem too little read, had exclaimed in the well-known lines,—

> "Soon shall thy arm, unconquered steam, afar
> Drag the slow barge, and urge the flying car."

The fame of the elder Darwin has been eclipsed by his younger relative; but he deserves to be remembered if it were only for the fact that he was the companion, friend, and adviser of James Watt, in whose genius he was an enthusiastic believer, and from whom he probably drew the inspiration which prompted the lines. The genius of James Watt and George Stephenson has changed all this, and, in changing it, altered the conditions both of public and of private life throughout the world. Darwin was not the only man of that time who looked forward with confidence to the ultimate victories of steam. Godwin, in his work, published in 1793, entitled *Political Justice*, a book full of bold, if very doubtful speculation, argues that since the discovery of the steam engine, the amount of manual labour required for the cultivation of the land was certain to be diminished. He says, in a passage which has been often referred to—"Hereafter, it is by no means clear that the most extensive operations will not be within the reach of one man; or, to make use of a familiar instance, that a plough may not be turned into a field and perform its office without the need of superintendence. It was in this sense," he continues, "that the celebrated Franklin conjectured that mind would one day become omnipotent over matter," and now that the locomotive carries mankind to all ends of the earth, Godwin's sanguine suggestion has been all but realised.

There has been during this interval a still more powerful magician at work. To this audience I need not dwell on the triumphs of the future ruler of the world of science—electricity. But one illustration I may be permitted. Franklin was one of the first of the non-resident members elected by the Royal Society of Edinburgh. How little he thought when many years before he drew the electric spark from the cloud, that before a hundred years had sped, his experiment, but slightly modified, might convey a message from a meeting

of the Society in Edinburgh to one of its Fellows in New York, and bring back an answer before the meeting separated.

In slightly alluding to this scientific revolution, my object has been partly to illustrate the surroundings of 1783, and also to remind my hearers that of all the changes the century has seen, far the most important, and the deepest, have been the work of science. Increased facilities for inter-communication carry with them a complete change in the economical and social condition of the communities they affect. New wants, new customers, new ambitions, new possibilities, follow in their train by the operation of inevitable laws. What was a luxury before becomes an ordinary necessity thereafter. What was in fashion is obsolete, and what seemed chimerical may be accomplished. By this talisman we have seen, perhaps sometimes without due appreciation, many a social problem solved which had before seemed hopeless; and although in the process of transition some period of adaptation may be necessary, and some temporary hardship endured, the result in all cases must be beneficent, and is at all events beyond the power of lawgivers to control or to resist.

These last remarks are not without an application to that circle of remarkable Scotsmen who constituted the Founders of the Royal Society. They were not only prominent by intellect and cultivation, but they were each characteristic and distinctive. It would be as impossible to reproduce that circle now, as to restore the ancient lineaments, and Continental aspect, and Continental usages of the ancestral city where they flourished. Although the exodus to the North had already commenced, we do not associate the Founders of the Royal Society of Edinburgh with the Edinburgh of to-day, but with the tall tenements, the wynds and closes, the densely packed hive of educated and learned Scotsmen, as Goldsmith or Johnson found it; as it was in the early days of Kames and Monboddo, with its afternoon tea-drinkings and club suppers. The century which has changed so much has changed these things also. As far as external conditions go, no revolution could be more complete. It has been a change from cultivated homeliness to splendour, from frugal although dignified economy to as much domestic luxury as any community in Europe enjoys. While in 1801 the whole population of Edinburgh was little over 60,000, it

amounted by the census of 1881 to 230,000, spread over an area nearly ten times the former in superficial extent, and furnishing in every quarter splendid examples of urban architecture.

The Royal Society itself was the culmination of that signal reviviscence of literary enthusiasm and power, which, to her own astonishment and that of the world, took place in Scotland in the second half of the eighteenth century. Stunned at its commencement by the removal of the legislature, and all the social prestige which the seat of a legislature enjoys, speaking a language which ultra-patriotic Scotsmen still think the more classic of the two, but still barbarous in Southern ears, the educated Scot set himself with the energy of a Border chief to try if he could not invade the territory of his neighbour across the Tweed in the world of letters. With what measure of rapid success the daring attempt was crowned the names of David Hume, Adam Smith, and William Robertson attest to this day. How it came that a knot of Scots philosophers, who used their own vernacular in familiar intercourse, should have become examples, not of thought only, but of style, to Englishmen, might admit of more detailed illustration than I can give it here. But very soon these literary chiefs from the North became famous and popular among London men of letters, as well as with the public. I find David Hume writing from London to Adam Smith on the publication of his *Theory of Moral Sentiments* in 1759, "that he had sent a copy of the book to some of his acquaintances, and among the rest to Lord Lyttleton and Horace Walpole;" and to Mr Burke, an Irish gentleman, he says, "who has lately written a very pretty treatise on the Sublime." On the other hand, in Mr Cosmo Innes' pleasant *Memoir of Professor Dalzel*, who, as we shall see, was a member, and one of the secretaries of the Royal Society at its foundation, he quotes a letter from the Professor to Sir Robert Liston in 1776, in which he says—"There is published also a first volume, quarto, of a *History of the Decline and Fall of the Roman Empire*, by Edward Gibbon, Esq., a member of Parliament," an expression which may well be placed alongside of Hume's reference to "Mr Burke as an Irish gentleman." A month before, in April 1776, this same Mr Gibbon wrote to Dr Adam Ferguson from London—"I have always looked up with the most sincere respect towards the northern part of our island, whither taste and philosophy seemed to

have retired from the smoke and hurry of this immense capital." He goes on to say, "What an excellent work is that with which our common friend, Mr Adam Smith, has enriched the public—an extensive science in a single book, and the most profound ideas expressed in the most perspicuous language." In 1776 we find Adam Smith a member of the "Club," founded in London by Johnson and Goldsmith; and the following lines by Dr Barnard (I quote from Dugald Stewart's *Life of Smith*, read to the Royal Society) indicate a position of respect in that circle:—

> "If I have thoughts, and can't express 'em,
> Gibbon shall teach me how to dress 'em
> In words select and terse.
> Jones teach me modesty and Greek,
> Smith how to think, Burke how to speak,
> And Beauclerk to converse."

I was amused to find that the admission of Smith to the "Club" excited the intense jealousy of James Boswell, who, in a letter to Mr Temple, one of those published a few years ago—says loftily, "Smith too is now of our Club. It has lost its select merit."

It is, however, to Dr Robertson and Lord Kames that we are mainly indebted for the idea of the Royal Society, and for the successful issue of the project. It sprung partly, of course, out of the example of the Royal Society of London. But its immediate antecedent was the Philosophical Society, which had been founded nearly fifty years before by the celebrated M'Laurin, and contained many distinguished names. Lord Kames became its president, and raised it to considerable distinction, both in science and literature, although that vigorous and versatile thinker and writer did not live to witness the commencement of the new institution. Dr Robertson's plan was to absorb this Society and all its members in a new Institute, on the model of the Berlin Academy of Sciences, for the prosecution both of Physical Science and of Literature.

I find from the minutes of the first meeting that the Society were of opinion that the College Library was an inconvenient place for their usual meetings, and a committee was appointed to find one more suitable, apparently without success, for they continued to be held in the library for twenty-three years, when the Society migrated to the Physicians' Hall in George Street in 1807. They afterwards

purchased No. 40 George Street, in which the meetings were held until they obtained their present rooms in the Royal Institution. At a subsequent meeting, held on the 4th of August 1783, it was resolved that the Society should be divided into two classes, which should meet and deliberate separately, to be called the Physical Class, and the Literary class, with separate office-bearers. But I have detained you too long on the threshold by this desultory exordium. Let us now draw up the curtain, and display the Founders of the Royal Society.

The first President was Henry, Duke of Buccleuch, who had rendered great assistance in obtaining the Charter. The Vice-Presidents were the Right Hon. Henry Dundas, and Sir Thomas Miller, the Lord Justice-Clerk.

I forbear to go over the names of what may be called the original members of the Society. I include in that term all who were elected within the first ten years. All the members of the Philosophical were assumed without ballot; the rest, to the number of more than a hundred, were elected by ballot, and a general invitation was made to the Lords of Session to join. These were the ordinary resident members. There was also a list of non-resident members, which comprised nearly as many. Of the ordinary resident members there is hardly a name which is not known—I might say conspicuous, in the annals of Scotland at that time. Twelve of the Lords of Session accepted the invitation, including the Lord-President, the Lord Justice-Clerk, and the Lord Chief Baron of the day; upwards of twenty professors, with Principal Robertson at their head; twenty-two members of the Bar, including Sir Ilay Campbell, the Lord Advocate—and of these at least fourteen rose afterwards to the bench; the medical contingent included Monro, Gregory, Cullen, and Home; and the non-resident list contained the names of the Duke of Buccleuch, the Earl of Morton, the Earl of Bute, the Earl of Selkirk, Lord Daer, James Stuart Mackenzie, the Lord Privy Seal, Sir George Clerk Maxwell of Penicuick, Sir James Hall of Dunglass, and many other familiar names. But I select from the list those of the members on whom fell the burden of the real work; and I venture to say that no city in Europe could have brought together a more distinguished circle. They were—Ilay Campbell, Henry Dundas, Joseph Black, James Hutton, John Play-

fair, Adam Smith, William Robertson, Dugald Stewart, Adam Fergusson, Alexander Monro (*secundus*), James Gregory, Henry Mackenzie, Allan Maconochie, and William Miller of Glenlee. I ought to add to these Sir James Hall of Dunglass and Sir George Maxwell of Penicuick. Some of these names are European, all are celebrated, and these were men who for the most part did not merely contribute the lustre of their names to the infant association, but lent the practical vigour of their great intellectual power to aid in the first steps of its progress. And very soon the impress thus stamped on the Society began to establish its reputation in the world, and it took no undistinguished place among the learned societies of Europe. I find the names of Goethe and Buffon among the original foreign members; and although the events of the next twenty years interrupted our relations with the Continent, by the time the Society had completed the half century, there was scarcely a distinguished *savant* in Europe who had not joined or been invited into our ranks.

In the physical class were four men who rose to great positions in the scientific world, and to whom the Society were greatly indebted for its general reputation, and for the vigour and efficiency with which their proceedings commenced. They were James Hutton, Joseph Black, John Playfair, and Dugald Stewart. Hutton and Black were then in the zenith of their fame, and have left a strong impress on the first years of our Society. Hutton was a most assiduous and energetic member. He had the distinction in the very first volume of the *Transactions* of lighting up two scientific conflagrations which blazed fiercely throughout Europe for many years afterwards. One was his theory of the earth, over which the Neptunists and Vulcanists fought with much fury, and the flames of which are perhaps not altogether extinct. Much has been learned on these subjects since that time. Whether the world of geology has been fused into a coherent mass by reason of this combustion I need not inquire. There have been theories of the earth since then, and possibly the slumbering embers may be rekindled. The other controversy was of narrower dimensions, and related to a paper of Hutton's on the "Theory of Rain," which was strongly attacked by M. de Luc, a French philosopher, and defended by Hutton in the *Transactions* with not a little asperity. That Hutton should have succeeded in the very outset of the

Society's labours in setting the philosophers of Europe by the ears, first about the fires beneath the earth, and secondly about the rain which falls from the heavens, is creditable at least to his energy. Into the merits of these controversies it is no part of my province to inquire; but I am desirous, in this review of the Society's early days, to revert with gratitude and respect to the memory of one whose labours on behalf of the Society were invaluable. From 1783 until his death in 1797 not a year went by in which our *Transactions* were not enriched by his vigorous conceptions.

Hutton was an observer and a thinker of remarkable originality and power. He had been a lawyer, a medical practitioner, a farmer, and an agriculturist, before he became known as a natural philosopher. Vigorous in thought and full of enthusiasm, he is said to have been as brilliant in conversation as he was obscure in his written style. Professor Playfair did for Hutton's theory of the earth what Dumont did for Bentham, and rendered his strong but obscurely expressed reasoning into clear and pellucid language.

I ought, in justice to his great services to the Society, and his undoubted ability, to have coupled with the name of Hutton that of Sir James Hall of Dunglass, who was one of our most energetic members, and held the position of President for many years. He was a friend and admirer of Hutton's, but, as he tells us, was at first entirely incredulous as to his theory of the earth, and it was only by the charm of his conversation, and verbal explanations far more lucid than his written style, that he at last adopted his views. It, however, occurred to Hall that if heat and pressure had produced the effects attributed to them by Hutton, the truth of the theory might be tested by actual experiment. Hutton discouraged this view, thinking that the heat to which these appearances were due must have been so much more intense than any which could be artificially produced, that no satisfactory results could be hoped for. Hall had so much respect for his friend that he refrained from any public notice of his experiments during Hutton's life; but after Hutton's death in 1797 resumed them with great ardour, and communicated the results in two papers read to the Society—one on the composition of Whinstone and Lava, read in 1798, and a second most elaborate account of upwards of five hundred experiments, read in 1805. These experiments were conducted with immense perse-

verance, considerable expense, and varying results. They have, however, not been without fame and favour in the scientific world, for I found, in the library of the Society, thanks to the attention of our Librarian, a work and an accompanying letter which indicate more powerfully than any words of mine could do, what interest and importance is still attached to the results of his experiments by men of science on the Continent. The letter is addressed to the President of the Royal Society of Edinburgh by M. Daubrée, who therein mentions that he is President of the Academy of Sciences of the Institute of France; it is dated in June 1879, and was received by my predecessor in the chair. It is in the following terms (I translate the substance of it). He requests the President to beg of the Society to accept from him a copy of a work which he is in the course of publishing, entitled *Synthetic Studies in Experimental Geology.* He proceeds—"It was on the soil of Scotland that the powerful and fertile genius of Hutton was inspired, and it was in the *Transactions* of your celebrated Society that James Hall published in the beginning of the century two papers of high importance to experimental geology. My expression of gratitude (*hommage*) is thus not without good reason." The work itself is a record of a series of most elaborate experiments, proceeding avowedly on Hutton's theory, and on the lines of Hall, accompanied by illustrative drawings, and intended to exhibit the effects of various mechanical agents in combination with heat or fusion on the materials of the crust of the earth.

The scientific merit of these views I do not pretend to judge; but it is at least a striking tribute to our Founders to find that their labours at the commencement of the century should be so highly appreciated by the world at large close on the end of it.

Black, again, was a Frenchman by birth, although his parents were British, and he was nearly related to Adam Smith and to Adam Ferguson. He came to Scotland when he was about twelve years old, and long before the institution of the Royal Society he had risen to the front rank of European chemists; his discoveries on pneumatic chemistry and latent heat having laid the foundation of much that is valuable in subsequent investigations, and opened a course of inquiry pursued with great ability in our own *Transactions* by Leslie, and Brewster, and Forbes. He took a great interest

in the Society, although he only contributed one paper of importance, on "The Hot Springs of Iceland." But no man has left a greater reputation behind him. I have said that Black was a relative of Adam Smith, who was on terms of the greatest intimacy with him and Hutton, and loved nothing so much as to get the philosophers together at what he called an Oyster Club, and listen to their talk. He appointed Black and Hutton as his joint-executors. Ferguson was also a relative, and Cockburn sketches what he recollects of each. He says of Ferguson—"I never heard of his dining out except at his relative Joseph Black's, where his son, Sir Adam (the friend of Scott) used to say it was delightful to see the two philosophers rioting over a boiled turnip." Cockburn used to watch Joseph Black from his father's house in George Square, and thus describes him :—

"He was a striking and beautiful person; tall, very thin, and cadaverously pale; his hair carefully powdered, although there was little of it, excepting what was collected into a long thin queue; his eyes dark, clear, and large, like deep pools of pure water. He wore black speckless clothes, silk stockings, silver buckles, and either a slim green silk umbrella or a genteel brown cane. The general air and frame were feeble and slender. The wildest boy respected Black. No boy could be irreverent towards a man so pale, so elegant, and so illustrious. So he glided like a spirit through our rather mischievous sportiveness unharmed."

The two others I have mentioned were too famous in their day, and are so still, to require to be, or to admit of being, described here. John Playfair and Dugald Stewart were men who by themselves could have raised to distinction any circle to which they belonged. Both of them were men of great versatility, and within the walls of the Royal Society capable of filling a foremost place, whether in the fields of exact science or in those of literature or mental philosophy.

Dugald Stewart's contributions to the *Transactions* are not so numerous as those of Playfair, but no man had more influence in moulding the tone and cast of thought prevalent amongst the cultivated class of his countrymen than that most popular and most eloquent instructor of youth.

But no one can study these volumes of the *Transactions*, as I have done, without feeling that for the first two decades of the existence of the Royal Society Playfair was the soul and life of the institution. His versatility and power have impressed me exceedingly, high as was the estimate I had previously formed of him. Profound and transparently clear, whatever might be the topic, he bears about him a far-reaching vigour which never flags. Whether it be the Origin and Investigation of Porisms, or the Astronomy of the Brahmins, or their Trigonometrical Calculations or Meteorological Tables, or a Double Rainbow, nothing seems too great or too small for him. Some of his obituary notices are fine pieces of English composition; in particular, his notice of Dr William Stewart and of Hutton, and his fragment on John Clerk of Eldin, which is printed in the ninth volume of the *Transactions*.

In looking through the list of members towards the commencement of the Society, two attracted my attention—from no special connection between them, excepting that they both were members of Johnson's Club, and both were celebrated in Goldsmith's poem of "Retaliation." The first was one which, by itself, was sufficient to confer distinction on any assembly, however distinguished, that of Edmund Burke, who, according to Goldsmith's cynical lines—

> "Born for the universe, narrowed his mind,
> And so partly gave up what was meant for mankind."

When I first observed the name, I wondered through what channel the great Irishman came into that company. Dalzel's *Memoirs*, however, make that clear. Burke was that year (1784) Lord Rector of Glasgow University, and on his return from his installation paid a visit to Lord Maitland at Hatton House, and there Dalzel met him, was charmed by his conversation, and recruited him for the Royal Society. I am not aware that he was in Edinburgh on any other occasion. Dalzel writes to Sir Robert Liston on the 20th of April 1784—"Our Royal Society is going on extremely well. I have proposed Mr Burke and you as new members." Next month he informs Liston that he was unanimously chosen a member, "which," he says, "was not the case with Mr Burke. He was chosen, but not unanimously—there were several black balls;" and the Professor proceeds to moralise on the occasion. There is no

need that we should do so. It is not in the least surprising that in those days the very fact of his renown should have induced one or two men in any assemblage to doubt whether, born for the universe or no, he was specially born for the Royal Society; and had the event occurred ten years later, the discontented might have been as numerous, but it is possible they might not have been the same.

The other name, although well entitled to remembrance on account of its owner's accomplishments and learning, owes its principal notoriety now to Goldsmith's gibe. It was that of Caleb Whitfoord—the merry Whitefoord of the "Retaliation"—of whom the author says—

> "For thy sake I'll admit,
> That a Scot may have hnmour, I had almost said wit."

Now, Goldsmith had a very genuine vein of wit and humour himself, as all the world knows, and was a very good judge of it in others. It must not be supposed that his knowledge of Scotsmen was confined to those he encountered south of the Tweed, for he spent one year at least, I rather think two, in 1752, as a medical student in Edinburgh, attended Dr Monro *secundus*, and was, as Mr Forster in his Life tell us, a friend of Joseph Black's. If so, I cannot help thinking he must have neglected his opportunities, if he found no humour in the circle in which Black moved. I have not time to unravel the mystery of Goldsmith's life in Edinburgh farther, for what he did while there, or when or why he quitted it, is left in great obscurity; but at least the Royal Society need not wince, for although wit and humour cannot be said to be the characteristic of our *Transactions*, there was one Scotsman who spread the fame of Scottish humour as widely as that of the Vicar of Wakefield—he was President of the Royal Society, and his name was Walter Scott.

There are many curious and interesting bypaths, both of science and literature, traversed in these earlier volumes. In 1787 Mr George Wallace read a paper, which he did not incline to have printed in the *Transactions*, which I regret, for it related to a subject the interest of which has not ceased by the lapse of nearly a century. Its title was "On the Causes of the Disagreeableness and Coldness of the East Winds." As I fear there is little reason

to think that the east wind has become less disagreeable or cold since that date, it might have been consolatory to know to what these attributes were due. At all events the question remains unfortunately as prominently for determination in 1884 as it existed in 1787.

In the first volume of the *Transactions* a very singular problem was presented through Mr Adam Smith to the Society, along with other learned bodies in Europe, by a Hungarian nobleman, Count Windischgratz, and a prize was offered by him of 1000 ducats for the best solution of it, and of 500 ducats for an approximation to a solution. It was a bold effort of philanthropy, for its object was the abolition of lawyers for the future. The problem was addressed to the learned of all nations. It was couched in Latin, but was in substance this :—"To find formulæ by which any person might bind himself, or transfer any property to another, from any motive, or under any conditions, the formulæ to be such as should fit every possible case, and be as free from doubt, and as little liable to controversy, as the terms used in mathematics." I suppose that the prospect here held out of dispensing for the future with the least popular of the learned professions, inclined the Society to entertain it favourably, for they proceeded to invite solutions of the problem, and three were received by them. In 1788 we find it recorded in the minutes that Mr Commissioner Smith (for so the author of the *Wealth of Nations* was designed) reported the opinion of the committee that none of the three dissertations amounted to a solution, or an approximation to a solution of that problem; but that one of these, with a certain motto, although neither a solution or an approximation to a solution, was a work of great merit; and Mr Fraser Tytler was instructed to inform Count Windischgratz of their opinion. Whether this meritorious dissertation obtained the 500 ducats or no, we are not informed; but as lawyers continue to flourish, and legal terminology to produce disputes as prolifically as ever, it seems clear that the author had not earned them.

Now that we have an observatory on Ben Nevis, our successors at the end of next century will know accurately the conditions of the climate under which the hundred years have been spent. There are, however, some details scattered over these volumes which are sufficiently interesting, although whether they show any material

alteration on our seasons, may be doubtful. The only cheering fact which they disclose is that the first set of returns do not support the idea that the mean temperature in the olden time was higher than it is now. There are two sets of returns printed in the first volume of the *Transactions*, one kept at Branxholm, from 1773 to 1783, communicated by the Duke of Buccleuch, who was the first President of the Society, and the second by Mr Macgowan, kept at Hawkhill, near Edinburgh, from 1770 to 1776. In the first, the mean temperature of the ten years is 44°, in the second 45°—not a very genial retrospect. Things must have been somewhat discouraging for the farmers in 1782, for a paper is noticed in the second volume of the *Transactions*, by Dr Roebuck of Sheffield, who was the manager of the Carron Iron Works, recommending farmers not to cut their corn green in October, although there was ice three quarters of an inch thick at Borrowstounness, because corn would fill at a temperature of 43°. Things looked brighter from 1794 to 1799, for which years we have results furnished by Playfair. For the first three years, 1794, 1795, and 1796, the mean temperature was 48° ; and that although 1795 was one of the most severe winters on record, the thermometer having stood frequently several degrees below zero, and a continuous frost having lasted for fifty-three days. The mean temperature in 1794, however, was 50°. The account of the great frost of 1795, which is given in the *Transactions*, is well worth referring to. In the next three years the mean temperature was 48°, that of 1798 being 49°-28°. Of this year (1798) Playfair says that the climate of this part of the island hardly admits of a finer season.

No tables were furnished to the Society in continuation of those of Professor Playfair until 1830, when fortunately Dr Barnes of Carlisle communicated to the Society a series of meteorological tables kept at Carlisle for the first twenty-four years of the century. The results seem mainly to concur with those of Professor Playfair. The mean temperature for the twenty-four years being 47°, being 3 degrees higher than the average of the ten years from 1773 to 1783 at Branxholm, and 2 degrees higher than the mean temperature of the years from 1770 to 1776 at Hawkhill. The highest temperature I have noted in these returns is that of May 1807, when the thermometer stood at 85° at Carlisle, and the heat on the 5th of August 1770, when the thermometer at Hawkhill was

at 81°. The two years of this century in which the mean temperature was the highest were 1811 and 1822, in both of which years it was 49°.

Of the purely scientific part of the Royal Society's work for the first fifteen years of its labours, while Hutton and Black and Playfair and Stewart were in full vigour, it is not too much to say it was brilliant, full of interest, full of power, and full of enthusiasm. The first great Founders, of course, gradually waned, and all such associations are necessarily subjected to alternations of the tide; but as the tale goes on, the mathematical papers begin to bear the names of John Leslie and William Wallace. We encounter Walter Scott in 1800, in 1808 the name of David Brewster, and in 1811 that of Sir Thomas Makdougall Brisbane, whose names adorned and whose labours were in the future the prop and stay of the Society. Of Scott I need not speak, but of the services rendered by Brewster it is impossible to express myself too strongly. He too, like Playfair, had a mind of a rare versatility; he could observe as well as draw from his own resources. He could reason as well as describe. He could build a framework of sound deduction from the most unpromising hypothesis, and work out with unflagging spirit the thread of demonstration, however slender. In some respects he differed from some of his contemporaries or predecessors. He did not for the most part shrink from giving the Society the benefit of his present thoughts and current experiments. Sometimes they were imperfect, sometimes perhaps even crude, but always full of acuteness, novelty, and genius. Had I had the scientific knowledge essential to the task, nothing I think could have been more interesting than to have traced Sir David Brewster's first speculations on light and heat contributed to the Society to the end of his career, and to mark and observe how great results gradually crowded on his canvas, to fill in the first slight and imperfect sketch. He was the most prolific contributor of his day; nor do I think that any one but himself in those times could have kept the fire lighted by Hutton and Playfair burning so brilliantly. For it is not to be disguised that in the heat of the continental struggle an air of languor creeps over the proceedings. The joyous enthusiasm of 1783 refuses to be invoked, and is solicited in vain. Nor is it wonderful, when the Gauls were so nearly at our gates, the safety of our own commonwealth should have been comparatively our only care. But when 1815 had arrived,

and men's minds, set free from the long anxiety, had again tranquillity to cultivate the arts of peace, the energy of the rebound was great, and the history of British science has been one continued triumph ever since. By the exertions of Brewster and Brisbane, and many other Associates, our Society again began to flourish, both leading and following the course of discovery as the stream flowed on. Both of these men continued to be the pride and ornament of the Society long after the expiration of that half century which I have assigned to myself as my limit. Sir Thomas Brisbane succeeded Sir Walter Scott as President in 1832, and survived until 1860. Long before that a new generation had surrounded the veteran philosophers, and their destiny has been to recount and carry forward discoveries of which even Brewster and Brisbane hardly dreamt. But the merits and successes of these later heroes must be the theme of some future historian, for at present, although posterity may think them braver sons of brave sires, they and their reputation are too close at hand to be properly treated of. Some names, indeed, contemporary with ourselves, but too early lost, I should like to have mentioned with a word of commemoration; but, on the whole, I have thought it better to adhere to my original programme.

I mentioned in the outset of these remarks that the Society, as originally constituted, was divided into two classes,—the Physical and the Literary,—and that these classes were to meet separately. I do not think this separation was politic; and it is impossible to deny that it very early proved a failure. For some years the literary side of the Society was maintained with considerable spirit and vigour, and some of the papers printed in the *Transactions* will repay perusal. Mr Maclaurin's paper, to prove that Troy was not taken by the Greeks, is a bold, learned, and not unsuccessful challenge of Homer's historical accuracy; and since Schlieman's recent explanations, perhaps more reason has been shown for his doubts. M. Chevalier contributed an elaborate paper on the Plain of Troy, in French, which attracted attention, and obtained some reputation on the Continent. One of the most important contributions to this department of the Society's labours is a paper by Henry Mackenzie on the German Stage, written at a period when German literature was little known or appreciated in this country, and composed in the light, elegant style characteristic of the author. There is also in the second volume of the *Transactions* a scholarly and interesting

paper by Dr Beattie on the Sixth Book of Virgil's *Euclid*, read in 1787. Altogether, however, this class or section of the Society did not command the success which attended the physical. As time went on, there seemed to be a want of material, and the papers dwindled down to somewhat pedantic dissertations on grammar, on moods of verbs, on pronouns, on the Greek letter sigma, on the Greek Δϵ, on the necessity for defining synonymous terms, and topics of this class, which although valued by and probably interesting to a limited class of philologists, were not animated in themselves, nor likely to excite enthusiasm on a general audience. I was quite prepared, accordingly, to find that the result occurred which circumstances foreshadowed. The following entries occur in the Minutes:—

"1793.—There being no business for the stated days of meeting in April, June, July, and November, no meetings were then held."

The same entry occurs in 1794; and the Literary class thus practically perished of inanition ten years after the foundation of the Society; and in 1808 the minute-book of that class ceases altogether. There has been no separate Literary class since the new rules passed in 1811.

It is not difficult to trace the causes which led to the continuance of this. In 1783 there had been a wave of literary revival passing over Scotland ever since the middle of the century, and our prose writers, Hume, Robertson, Blair, and others of that circle, including specially Henry Mackenzie, had raised a spirit of enthusiasm for such pursuits. But such fashions rapidly change. The immense effects produced on human thought by the French Revolution gave a fresh impulse and a new direction to literary taste. New outlets, more profitable than the supply of our *Transactions*, soon afterwards opened to the literary world. *The Edinburgh* and *Quarterly Reviews;* Byron, Scott, Wordsworth, Coleridge, and Campbell inaugurated a new era, under which the old ways became unfashionable, and the old taste obsolete. Matters stood quite differently with the Physical class. In that opinions may grow obsolete, but the theme never. Fresh ground is always to be found. So men turned out with alacrity to hear about the Vulcanists and Neptunists, or latent heat or the latest geometrical problem, who would not stir from their homes to be told the use of a subjunctive, or Dr Parr's derivation of the word "*sublimis.*"

In its former shape it would be impossible to revive the Literary class. Still I think it would lighten and enliven our meetings here if the graver matters of the physical class were sometimes interspersed with contributions of a literary nature. This I see plainly cannot be done without some labour, and some concert among the Fellows. If I can aid in any such scheme, I need not say that any assistance I can give would be willingly rendered.

Before quitting this subject of the Literary class, I would remark that the most valuable papers of this class are the Obituary Notices, which in general are good examples of vigorous and elegant writing, and are interesting as authentic records of celebrated men. The three notices by Dugald Stewart of Adam Smith, Principal Robertson, and Thomas Reid are printed in Stewart's Life by Sir W. Hamilton, and are masterpieces of biography. Two others in particular arrested my attention. The first, a very remarkable paper by the Rev. Mr Alison on Lord Woodhouselee, and the other, a charming biography of Lord Abercromby by Henry Mackenzie.

One class of our Founders I feel I have treated with scant justice—I mean those of the legal profession. The truth is they furnished a large and available contingent, more perhaps in the way of influence than in that of contribution. But I have not done so from undervaluing the aid they gave, but because to estimate properly their assistance would have led me into inquiries which would have swelled this paper—already, I fear, too prolix—beyond reasonable dimensions. It would have involved a dissertation on the *Mirror* and the *Lounger*, and the state of periodical literature in Scotland at the close of last century. The men whom Henry Mackenzie gathered round him were almost all lawyers, and lawyers of note—Lord Abercromby, Lord Craig, Lord Dreghorn, and Lord Bannatyne were men well deserving of commemoration. It is true, our *Transactions* contain few contributions from their pen; but the true value of such institutions as the Royal Society is found mainly not in the contributions to the evening's interest, but in the enthusiasm they foster and the inquiries they excite. One man who indicates earnestness in the prosecution of a science or an experiment, may do more to encourage the spirit and love of investigation than the more constant contributor. It is the social tribunal in which, after all, such institutious as ours must depend; and to excite general attention, and stimulate rivalry, and inspire the generous emulation to

walk in the footsteps of our predecessors, and to keep the torch which they have handed down to us burning brightly, is to show ourselves worthy of our great inheritance.

I cannot finish my remarks without a tribute of respect to the able and vigorous intellect of the man I just now mentioned—I mean Henry Mackenzie. The Society owes him many obligations; so does his country. He created a style of periodical literature in Scotland which has borne rich fruit; and although even he could not prolong the life of the literary class, his own extended to a patriarchal age, in which he saw the lessons he had taught produce an exuberant harvest. As a pendant to some of Cockburn's sketches of the olden time, I finish these desultory outlines by a quotation from another writer. The author of Peter's Letters—I suppose I may say John Gibson Lockhart—describes a dinner party about 1818, at the house of Henry Mackenzie, at which the only other guest was another of our founders Adam Rolland, who, if he only lived on Raeburn's canvas, could not have been forgotten.

He says—"The only visitor besides myself was an old friend, and indeed contemporary with Mackenzie, a Mr Roland, who was in his time at the head of the legal profession in Scotland, but who has now lived for several years in retirement. I have never seen a finer specimen, both in appearance and manner, of the old Scottish gentleman.

"It was a delightful thing to see these two old men, who rendered themselves eminent in two so different walks of exertion, meeting together in the quiet evening of their days, to enjoy in the company of each other every luxury which intellectual communication can afford, heightened by the yet richer luxury of talking over the feelings of times to which they almost alone are not strangers." "They are both perfectly men of the world, and there was not the least tinge of professional pedantry in their conversation." He proceeds—"According to the picture they gave, the style of social intercourse in this city, in their younger days, seems indeed to have been wonderfully easy and captivating. At that time not one stone of the New Town, in which they and all the fashionable inhabitants of Edinburgh now reside, had been erected. The whole of the genteel population lived crowded together in those tall citadels of the Old Town. Their houses were small, but abundantly neat and comfortable, and the labour which it cost to ascend to one of them was sure to be repaid by a hearty welcome from its possessor. The style of

visiting altogether was as different as possible from the ceremonious sort of fashion now in vogue." He concludes his description by saying, "If I were to take the evening I spent in listening to its history as a fair specimen of the 'Auld Time,' I should be almost inclined to reverse the words of the Laureate, and say—

> Of all places, and all times of earth,
> Did fate grant choice of time and place to men,
> Wise choice might be their '*Scotland*,' and their '*Then*.'"

Enough for the present, this retrospect, and the slender tribute I have attempted to pay to the memory and labours of a masculine and powerful generation. That we have built on their discoveries, and have learned even by their errors, is quite true; for the history of the second half of the century exhibits science far in advance of 1783, and even of 1833. In 1783 geology was in its infancy. Palæontology was all but unknown. Cuvier was only then commencing his pursuits in comparative anatomy, which were to end in reproducing the forms of extinct life. The glacial epoch had not then been elucidated by the research and genius of Forbes and Agassiz, and the dynamic theory of heat was still unproclaimed. The wonders of the photographic art were unknown, even in 1833, for Talbot and Daguerre did not come on the scene for several years afterwards. In 1833 the apostle and disciples of evolution had not then broken ground on that vast field of inquiry. The ever-increasing development of the mysteries of light and sound, *spectrum analysis*, and the marvellous results which it has already furnished, and those which it promises, have in our day only heralded the advent of a new science. But, however far in advance of the Founders of the Royal Society the current philosophy may be, there was a robustness and characteristic individuality about the great men of that generation which we may not hope to see replaced.

We may assume, indeed we hope, that the close of the next century will find the progress of knowledge as far advanced beyond its present limits as we think that the science of to-day is beyond the point reached a century ago. We may be assured that before that time arrives, many surmises, still in the region of hypothesis, will have become certainties, and that many supposed certainties will have turned out fallacies. Many errors will have been corrected, many dogmas discredited, many theories confirmed or refuted at the bar of ascertained fact, as those of 1783 have been.

Yet even then will our successors, I trust, as we now do, stand reverently before the memory of our Founders. In their very lineaments, of which, as portrayed by the master hand of Raeburn, we saw many not far from this spot a few years ago, the vigour and originality of the men are written in characters not to be mistaken. Happy is the institution which can show such a muster-roll, and happy the country which can boast such sons. I take leave of my theme with the fervent hope and firm conviction that, in the century which we now inaugurate, the Royal Society will continue with like success the noble task to which by its Charter it is devoted, of investigating the hidden treasures of nature, and appropriating them to the benefit and happiness of mankind.

On the motion of the Hon. Lord M'Laren, a vote of thanks was accorded to the President for his address.

The following Communications were read:—

2. On the Microscopic Characters of Volcanic Ashes and Cosmic Dust, and their Distribution in the Deep Sea Deposits. By Mr John Murray and Mons. A. Renard. Communicated by Mr John Murray.

In the Session of 1876, Mr John Murray communicated to this Society a paper on the distribution of volcanic débris over the floor of the ocean,* and in it announced the discovery of cosmic dust in deep sea deposits. It was shown that at points, where neither the action of waves, rivers, or currents can transport the débris of continents, volcanic materials play the most important rôle in the formation of the mineral constituents of the deep sea deposits. It was pointed out that pumice, on account of its structure, was able to float to great distances, but in time became waterlogged and sank to the bottom, there to decompose. On the other hand, incoherent volcanic matters, ejected in the form of lapilli, sand, and ashes, into the higher regions of the atmosphere, may, *ceteris paribus*, be conveyed, in consequence of their small dimensions and structure, to greater distances than other mineral particles derived from the continents. The possibility was also admitted that submarine volcanic eruptions might also contribute to the accumulation of

* *Proc. Roy. Soc. Edin.*, 1876–77.

those silicates and pyrogenous minerals and rocks, whose microscopic characters and distribution at the bottom of the sea we shall presently point out.

During the past few years we have added greatly to the observations which were the subject of Mr Murray's communication. The present paper has been suggested by the striking analogy which exists between the volcanic products we have found in all deep sea sediments and the ashes and incoherent products of a recent celebrated eruption,—that of Krakatoa. The remarkable meteorological phenomena we have recently witnessed have been attributed by some to the presence in the atmosphere of mineral particles derived from this volcanic eruption, and by others to that of cosmic dust. It is said that in several places in America, and even in Europe, matters have been collected which must be regarded as the ashes from Krakatoa, which have been suspended for several months in the upper currents of the atmosphere. The importance of this matter has been recognised by the Royal Society of London, which has appointed a committee of its members to collect all the documents and observations relative to the distribution of these ashes. The present state of the question induces us to make known some results of the detailed researches which we have undertaken upon similar subjects. We desire to make known to those who wish to study atmospheric dust, the distinctive microscopic characters by the aid of which we have been able to establish the volcanic or cosmic nature of certain particles found in deep sea deposits, and to show at the same time the enormous area of the ocean over which we have been able to detect their distribution.

We believe that no better example could be found in support of our interpretations than the microscopic study of the ashes from Krakatoa, whose mineralogical and chemical composition M. Renard * was the first to make known, and whose observations on this subject have been amply confirmed by the later researches of other mineralogists. On the other hand, the conditions under which floating pumice was found after that eruption agree perfectly with the interpretation given eight years ago by Mr Murray, rélative to the mode of transport of these vitreous matters, and of the accumulation of their triturated débris on the bottom of the ocean. We shall also

* "Les cendres volcaniques de l'éruption du Krakatau" (*Bull. Acad. Roy. de Belgique*, sér. 3, t. vi. No. 11 Séance du 3 Nov. 1883).

see how the sorting which takes place in the transport of the ashes of a volcano has its analogy in what we find in the deep sea deposits.

In the First Part of this communication we shall give the mineralogical description of the fragmentary products of Krakatoa, and consider generally the observations relative to these ashes. We shall also give the diagnostic characters of this volcanic dust, and of all similar particles which we find in deep sea deposits. In the Second Part, we will treat of the cosmic matters found in the abysmal regions of the ocean, to which Mr Murray was the first to draw attention, and discuss their origin and distribution.

First Part.

It is unnecessary to refer to the abundance of floating pumice, to its various degrees of alteration, to its conveyance by means of rivers, waves, and currents, and to its universal presence in deep sea deposits, which have been pointed out in some detail in Mr Murray's paper above referred to; but we will briefly recapitulate the characters of these volcanic matters, in accordance with the examination we have made of a large number of soundings and dredgings. We need not describe in detail the special characters of the lapilli which have been brought up in the dredge and sounding-rod from great depths. These fragments of more or less scoriaceous rocks belong to the same lithological varieties as those derived from terrestrial volcanoes. They consist of fragments of trachyte of various dimensions, of basalt, and, above all, of augite-andesite; the most remarkable, beyond all question, being lapilli of sideromelan, which are often entirely transformed into palagonite, and pass into the clay which is found so widely distributed, especially in the Pacific.

We do not propose here to take up in detail the wide distribution of the materials ejected from Krakatoa; we are engaged in collecting these, and will place the observations on maps along with those of Mr Buchan on the upper currents of the atmosphere, which will be published in the "Challenger" Reports.

Before, however, passing to the description of the ashes themselves we will briefly refer to some points touched upon by Mr Murray in his paper. It is there pointed out that, in regions far removed from coasts, rounded fragments of pumice were collected on the surface of the sea by means of the tow-net, and that, at certain points on the bottom of the ocean, the greater part of the deposit is composed

of vitreous splinters derived from the trituration of pumice stones. The description of the phenomena connected with the Krakatoa eruption gives us a complete explanation of these observations. The specimens of pumice from Krakatoa, which have been collected floating on the sea and which we have examined, are in like manner rounded. The angular surfaces are all worn away just as in pebbles; the only asperities to be observed consist of crystals and fragments of crystals, which project beyond the general surface of the vitreous matter, which last, on account of its structure, presents less resistance to wear and tear than the minerals which are embedded in it.

We may recall the fact that the Bay of Lampoung, in the Straits of Sunda, was blocked by the vast accumulation of pumice, formed in a few hours by the eruption of Krakatoa, which completely filled the bay. This floating bar of pumice stones was about 30 kilometres long, 1 kilometre broad, and 3 to 4 metres in depth, 2 or 3 metres of which were below the surface of the water, and 1 metre above. These numbers give about 150 millions of cubic metres of ejected matter. This moving elastic wall rose and fell with the waves and tide,* and was carried by currents thousands of miles from the point of eruption over the surface of the ocean. The rounded form of blocks of pumice met with everywhere floating on the surface of the sea, as well as of those samples which, after having floated some time, became waterlogged and sank to the bottom, may be perfectly explained if we remember the friability of this rock, and, at the same time, the agitation to which it is submitted by the waves, through which the pieces are continually being knocked against each other. We understand also how this wear and tear gives rise to an immense quantity of pulverulent pumice fragments, which contribute in a great measure to the formation of oceanic deposits. As a matter of fact, rounded fragments of pumice have been met with floating on the surface of every ocean, and during the last few years many samples have been sent to us by captains of ships and missionaries. As has been already pointed out, they are universally distributed in oceanic deposits, although frequently highly altered.

If it be easy to pronounce upon the volcanic nature of these larger fragments, it becomes, on the other hand, exceedingly difficult when we have to deal with particles reduced to powder, and when

* *Comptes rendus de l'Académie des Sciences*, 19 Nov. 1883, p. 1101.

recourse must be had to the microscope. Let us see what are the microscopic characters by which we recognise the particles of this dust.

We may here point out that it is not so much the presence of volcanic minerals which enables us in a marine sediment, as well as in an atmospheric dust like the ashes of Krakatoa, to recognise that the small fragments have an eruptive origin, as the microscopic structure of the small vitreous particles. It is well known that minerals reduced to small dimensions and irregularly fractured, as in the case of volcanic ashes, often lose their distinctive characters. Their size does not allow us to judge of their optical properties; their form, irregular and fragmentary, renders it difficult to determine the characteristic extinction of the species; the phenomena of coloration, of pleochroism, and the tint peculiar to the mineral, all lose so much of their intensity, that they no longer serve for the identification of isolated minerals like those of the volcanic ashes which we have to study. As a result of our observations, we believe that in most cases where a mineral, under the conditions we have just described, reaches dimensions less than 0·05 mm., its determination with certainty is no longer possible, and consequently its origin can no longer be established; whilst a vitreous fragment, like those of volcanic ashes or triturated pumice, continues to be discernible when its dimensions are less than 0·005 mm. A reason for showing that the absence or rarity of crystals, or of fragments of volcanic crystals, ought not to be taken as a proof that a sedimentary matter, either from the atmosphere or from the deep sea, is not of volcanic origin, is the sorting process to which these matters are subjected in the air and in the water, a phenomenon to which we shall presently recur.

The most reliable distinctive character is always found in the structure of the small vitreous particles which are derived from the trituration of pumice or have an analogous origin, inasmuch as they have been ejected from the volcano in the state of ash. The structure peculiar to these materials is seen in their fracture, which leaves its impress upon the smallest fragments of débris, in which the microscope can decipher no characteristic properties except such as have relation to form. In order to assure ourselves that these characters of pumice remain constant to the extreme limits of pulverisation, such as are employed in the preparation of silicates for

chemical analysis, we pounded in an agate mortar several varieties of pumice, and the powder thus produced clearly showed itself to be composed of particles in which were recognisable, with little trouble, the characters of the pumice-like material which is constantly met with in the sediments, and of which the ashes of Krakatoa give us beautiful examples. The diagnostic character to which we here make allusion rests on the distinctive peculiarities of incoherent volcanic products. What distinguishes them from lavas is not merely the extraordinary abundance of vitreous matters, but also the prodigious number of gas-bubbles which are enclosed by the pumice and vitreous volcanic sands and ashes. These bubbles are due to the expansion of the gases dissolved in the magma, which also determine the eruption. If we admit, as everything seems to show, that these incoherent volcanic matters are the products of the pulverisation of a fluid magma, we can understand that these particles, on cooling rapidly, will remain in the vitreous state, and, on the other hand, that the dissolved gases, yielding to the expansion, will form numerous pores which will become elongated owing to the mode of projection. It is the existence of these bubbles, or of such a filamentous structure, which points out to us the vitreous volcanic materials in spite of the great fineness of subdivision. It is also this structure which allows these bodies to be carried to such great distances from the scene of eruption.

The examination of the Krakatoa ashes, and of the dust resulting from the pulverisation of the pumice of that volcano, shows markedly the peculiarity due to the bullous structure. If this grey-green pulverulent matter be placed under the microscope it is seen to be composed of almost impalpable grains, with a mean diameter of 0·1 mm., which are almost exclusively colourless or brownish vitreous particles permeated by bubbles. The bubbles are rarely globular, but often elongated, as we have just pointed out, and they give a drawn-out appearance to the fragments. As often happens, several bubbles are elongated parallel to each other, and in this case, the pore becomes a simple streak; the fragment then assumes a fibrous texture, which may cause it to resemble at first sight a striated felspar or an organic remnant; but an examination of the outline will never allow of this confusion. If we examine the terminal contours and lines of these bubble-containing fragments, we never find that they are straight lines, but that

they show a ragged appearance, all the sinuosities being curvilinear. This mode of fracture is in correspondence with the vacuolated structure, and, just as in the porous pumice, the vitreous volcanic ashes are permeated by vacuoles; besides, everything goes to show that the fragmentary condition and the fresh fractures are due to a tension phenomenon which affects these vitreous matters in a manner analogous to what is observed in the "Rupert's drops."

Fig. 1.—Vitreous particles of the Ashes of Krakatoa, which fell at Batavia, 27th August 1883 ($\frac{1}{250}$).

We have pointed out that brown vitreous fragments are rare in the ashes of Krakatoa. These, however, contain skeletons of magnetic iron, and are devitrified by microliths.* It is scarcely necessary to add that the particles, whose form we have indicated, are isotropic. If under crossed nicols we sometimes see the field illuminated, this is due to crystals in the vitreous matter, or to phenomena of tension, which are sometimes observed in the neighbourhood of the bubbles.

These details on the microstructure of the vitreous particles from Krakatoa can be applied with most perfect exactitude to the volcanic dusts, which we have determined as such, in the deep sea deposits. In virtue of their bulbous structure, their dimensions, and their mode of projection, they are capable of being widely transported from the point of eruption by aerial currents. It must be admitted,

* Just as we can divide pumice microscopically according as it is acid or basic, so the products of its trituration may be recognised under the microscope, inasmuch as the former often give colourless and more elongated particles, while the fragments of basic pumice have a more pronounced tint and more rounded pores.

however, that in the deep sea sediments a very large part of these vitreous splinters has not been derived from the pulverised ejections from a volcano, but from the trituration of floating pumice, of which we have given above a striking example. It will be understood that it is scarcely possible to trace the difference between volcanic ashes, properly so called, and the products resulting from the pulverisation of floating pumice which we have just indicated. As in the incoherent products of Krakatoa, so we find spread out on the bottom of the sea many more vitreous particles, similar to those we have just described, than of true volcanic minerals. This is easily explained, however, when we remember how the distribution of volcanic dust takes place.

Let us now point out the minerals which can be determined with certainty in the ashes of this great eruption; and we may at once remark that they are the same which we have almost always found associated in the deposits with the splinters of glass. In general all the crystals are fractured, except those which are still embedded in a vitreous layer; this vitreous coating is often crackled and bullous. In the ashes of Krakatoa, however, we have not remarked the globules of glass which are often described as glued to the minerals of volcanic ashes, nor have we seen the drawn-out vitreous filaments resembling Peles hair. The minerals of the Krakatoa ashes which are susceptible of a rigorous determination belong to plagioclase, augite, rhombic pyroxene, and magnetite.* We shall presently see the peculiarity which distinguishes each of these species in the ashes.

Among the most frequent minerals, but poorly represented in comparison with the vitreous matter, plagioclase felspar comes first. This mineral has about the same dimensions as the vitreous fragments, and, with the exception of the crystals entirely enclosed in the pumice matter, is in the form of débris. Sometimes twins on the albite plan can be distinguished, and the results of analysis clearly indicate that it is triclinic felspar which should almost exclusively be found in this ash. But the most interesting crystals of plagio-

* Lately the works on these same ashes have made known as accidental elements pyrites, apatite, and perhaps biotite (?). It is to be remarked, however, that these minerals must be extremely rare in comparison with the vitreous matters and mineral species above-mentioned.

clase, and the most characteristic of this ash, although represented very rarely, are in the form of rhombic tables, extremely thin, and covered with a fine lacework of vitreous matter. We know that the crystals described by Penck * in a great number of lapilli and of volcanic ashes, upon the nature of which doubts have been expressed, belong incontestibly to the plagioclases, and represent an isomorphic mixture analagous to that of bytownite. It is to Mr Max Schuster † that we owe this specific determination. Having found in numerous sediments of the Pacific these same crystals in the form of rhombic tables, and possessing preparations which would be of great interest to him in his remarkable optical studies on the felspars, we submitted them to this ingenious mineralogist in order to confirm our determination. We believe it will be interesting to give a resumé here of the results of the observations of Mr Schuster, which are perfectly applicable to the characteristic crystals of felspar from Krakatoa, as well as to those which we have discovered in a great number of deep sea soundings.

This plagioclase occurs for the most part in flat tabular crystals with the clinopinakoid especially developed. Individuals of the columnar type, elongated in the direction of the edge P/M, are rare. These tabular crystals consist essentially of a combination of the clinopinakoid with P and x, more rarely with P, u, and y, and occasionally x and y appear together. In the first case the crystals have the form of a rhomb, in the second case they are elongated through the predominance of either x or P. The dimensions of those crystals which were examined and measured, lie between the line 0·61 mm. broad and 1 mm. long as maximum, and 0·015 mm. broad and 0·042 mm. long as minimum. The extinction of the plagioclase is negative. Its value was found to vary between 22° and 32° on the clinopinakoid, and between 8° and 16° on the basal plane. The average values of many measurements made on good crystals are as follows:—24° 12′, 25° 6′, and 29° 6′ on the clinopinakoid, 10° 42′ on the one side, and 10° 18′ on the other side of the twinning line, as this is shown on the basal plane.

* Penck, "Studien über lockere vulkanische Auswürflinge," *Zeitschr. d. deutsch. geol. Gesellsch.*, 1878.

† Schuster, "Bemerkungen zu E. Mallard's Abhandlung sur l'isomorphisme des feldspaths tricliniques, &c.," *Min. petr. Mitth.*, v. 1882, p. 194.

Polysynthetic individuals, made up of repeated twins on the albite plan, were very rarely observed. The felspar in its optical properties is thus seen to lie between labradorite and bytownite. The twin growths are particularly frequent and interesting on account of the structure of the individuals. In addition to those of the albite type, others were observed in which the edges P/M and P/K could be definitely determined as the axes of twinning, whilst P and K formed the twinning planes. The plane of composition was principally either P or M when penetration twins were not observed.

These fragments and crystals of plagioclase contain inclusions of vitreous matter, and sometimes grains of magnetite. Perhaps a small number of felspathic grains may belong to sanidine, the presence of which is insinuated by the percentage of potass indicated by the analysis which follow ($K_2O = 0{\cdot}97$ per cent.).

We have said that the pyroxenic minerals of the ash are augite and a rhombic pyroxene; we distinguish them by the microscope sometimes in the form of fragments—and this is usually the case—sometimes in the form of crystals, which we can isolate from the volcanic glass covering them by treating them with hydrofluoric acid. In the crystals of augite we distinguish the faces of a prism, of the brachypinakoid, and indications of the faces of a pyramid. This augite is pleochroic and has a greenish tint, and extinguishes in certain cases obliquely to the prismatic edges. It is this character which often permits it to be distinguished from rhombic pyroxene with which the augite is associated. The crystals of hypersthene are transparent, of a deep brown colour, strongly dichroic, with green and brown tints. They are in rectangular prisms terminated by a pyramid, and extinguish between crossed nicols parallel to their longitudinal edges. Magnetic iron, which is rather abundant in the ashes, is recognised in the form of grains and octahedrons. We have not been able to detect with certainty either hornblende or olivine. The largest grains of this ash are true microscopic lapilli, where we distinguish in a vitreous mass microlithic crystals of felspar, of magnetite, and more rarely of pyroxene. Finally, we observe with the microscope particles of an organic origin, which are easily recognisable by their fibrous and reticulated structure. These impurities may have been transported

by winds, or may have come from the ground where the ashes were collected.

In spite of all the uncertainties which the exact diagnoses of volcanic dust present, we can consider them often, from the point of view of their mineralogical composition, as analogous with the augite-andesites. We know, besides, that it is to these rocks that the lavas of the volcano of Krakatoa should be referred.

The ashes which fell at Batavia on the 27th August 1883, and samples of which were sent to Holland by M. Wolf, resident on that island, have been analysed with the following results:—

I. 1·119 grm. of substance dried at 110° C., and fused with carbonate of soda and potash, gave 0·7799 grm. of silica, 0·1754 grm. of alumina, 0·0911 grm. of peroxide of iron, 0·0401 grm. of lime, 0·398 grm. of pyrophosphate of magnesia, answering to 0·01434 grm. of magnesia.*

II. 1·222 grm. of substance dried at 110° C. gave 0·0335 grm. of loss on ignition (water, organic substances, chloride of sodium); the same substance treated with hydrofluoric and sulphuric acids gave 0·1161 grm. of chloride of sodium and potassium, and 0·0118 grm. of chloroplatinate of potassium, answering to 0·0118 grm. of potash and to 0·0188 grm. of chloride of potassium; by difference = 0·0973 grm. of chloride of sodium, answering to 0·05163 of soda.

III. 1·7287 grm. of substance dried at 110° C. was treated in a closed tube with hydrofluoric and sulphuric acid. The oxidation required 2·3 c.c. of permanganate of potash (1 c.c. = 0·0212 grm. FeO), answering to 0·047876 grm. of peroxide of iron.

	I.	II.	III.	
SiO_2	65·04	...	...	65·04
Al_2O_3	14·63	...	...	14·63
Fe_2O_3	4·47	...	...	4·47
FeO	...	...	2·82	2·82
MnO	traces	...	...	traces
MgO	1·20	...	...	1·20
CaO	3·34	...	...	3·34
K_2O	...	0·97	...	0·97
Na_2O	...	4·23	...	4·23
Loss	...	2·74	...	2·74
				99·44

It will be understood that it is barely possible to submit this analysis to discussion. The abundance of vitreous particles in the ashes renders illusory the calculation of the values obtained, and

* A recent determination of titanic acid has given 0·62 per cent. TiO_2.

the distribution of the substances among the different species of constituent minerals. This vitreous matter can indeed contain an indeterminate quantity of the different bases. On the other hand, the difficulties of the calculation are all the greater, as the constituent minerals of the ashes may contain, as isomorphs, the bases which the analysis suggests. It is none the less true, however, that the percentage composition expressed by the analysis supports the preceding mineralogical determinations, without permitting the species to be precisely determined. It agrees with the interpretation that the magma from which the ashes were formed belongs to the augite-andesites.

The vitreous and mineral fragments we have just described from the Krakatoa eruption being identical with those which we encounter in deep sea sediments, we may conclude that both have a similar origin. In certain cases, however, we have in place of augite a predominance of hornblende, and sometimes black mica is abundant. Again, we find more or less fragmentary crystals of peridote, of magnetite, of sanidine, and, more rarely, of leucite and of hauÿne. We can easily understand this variation in composition, following the nature of the magma from which the ashes collected in different regions of the sea were derived. But in all cases it is the predominance of vitreous particles, with their special structure, which indicates most clearly the volcanic nature of the inorganic constituents of a sediment.

If now we consider the conditions which govern the distribution of ashes in the atmosphere or at the bottom of the sea, we shall be able to show how it is that there is generally a predominance of vitreous particles in these ashes. In the first place, these are vitreous matters rather than minerals, properly so called, from the moment of ejection from the crater. Moreover, we should, in a general way, not expect to find that incoherent eruptive matters, which are spread out at a distance from the volcano, present a perfectly identical composition with those other loose products such as lapilli, volcanic bombs, and scoriæ, which are projected only a short distance from the focus of eruption. Even where there exists a perfect chemical and mineralogical identity, in the crater itself, between the lavas and the pulverulent materials of the same eruption (the supposition being that the ashes arise simply from the trituration of the lavas), we can easily understand that these latter, being carried far and wide

by the winds, must undergo a true sorting in their passage through the atmosphere, according to the specific gravity of the amorphous elements or crystalline constituents. It results from this, that according to the points where they are collected, volcanic ashes may, although belonging to the same eruption, present differences not only with respect to the size of the grains, but also with respect to the minerals.

In this method of transport it is evident that the vitreous particles, other things being equal, will be transported farthest from the centre. In the first place they are more abundant than the other particles, and again they possess in their chemical nature and in their structure, conditions which permit the aerial currents to take them up and carry them to great distances; they consist of a silicate in which the heavy bases are poorly represented as compared with the other constituent elements; they are filled with gaseous bubbles which lower their specific gravity, and at the same time are capable of being broken up into the minutest particles. The minerals with which they are associated at the moment of ejection from the crater are not, like them, filled with gaseous bubbles; they do not break up so easily into impalpable powder, for they are not porous, and are not in the same state of tension as the rapidly-cooled vitreous dust. Finally, many of these species are precisely those whose specific gravity is very high, on account of the bases entering into their composition. These minerals will not then be carried so far from the centre of eruption, and in all cases the vitreous particles are the essential ones in the atmospheric dusts derived from volcanic ashes.

We have a beautiful illustration of this in the ashes of Krakatoa. In proportion as the ashes are collected at a greater distance from a volcano, so are they less rich in minerals, and the quantity of vitreous matter predominates. According to a verbal communication from Professor Judd, the ashes collected at Japan contain only a relatively small proportion of pyroxene and magnetite.

If we wish to assure ourselves of the nature of an atmospheric dust, and, as has lately been frequently attempted in Europe, to show that the dust is really from the Krakatoa eruption, it is important above all to seek for the presence of vitreous fragments. The characters which we have indicated permit any one to recognise

them easily under the microscope. We would remark, however, that the presence of crystals, either of hypersthene, of augite, or of particles of magnetite in an atmospheric dust collected in Europe, does not prove in a certain manner that the dust belongs to the ashes from Krakatoa; for besides the difficulties of an exact mineralogical determination of the fragmentary elements, it is difficult to understand how these heavy minerals should have been carried by the aerial currents, while the vitreous dust is absent. As we have just shown, it is the contrary which should have taken place.

It results as a corollary from these considerations that the chemical composition of an ash may vary according to the point at which it has been collected, and it tends also, other things being equal, to become more acid the further it is removed from the centre of eruption. If we admit, for example, that the magma which gave birth to the ashes of Krakatoa is an augite-andesite, as everything seems to indicate, the percentage of silica (65 per cent.) which our analysis shows appears too high, but if we remember, what we have just said, that the ashes become deprived, during their passage through the atmosphere, of the heavier and more basic elements, it will be understood that the vitreous and felspathic materials, which have a lower specific gravity, and are, at the same time, more acid, will accumulate at points farthest from the volcano. It will be sufficient to have directed the attention to this fact to show how the percentage of silica in the ashes from the same eruption may vary according as they are collected at a variable distance from the crater.

The predominance of vitreous splinters in deep sea sediments far removed from coasts is even more pronounced than in volcanic ashes collected on land. This arises, as we indicated at the commencement, from the large quantity of pumice carried or projected into the ocean, whose trituration, which takes place so easily, gives origin to vitreous fragments difficult to distinguish from those projected from a volcano in the form of impalpable dust. In addition, we may state that in the distribution of volcanic materials on the bottom of the sea, the ashes are subjected to a mode of sorting having some analogy to that which takes place during transport through the atmosphere. When these ashes fall into the sea a separation takes place in the water; the heaviest particles

reach the bottom first, and then the lighter and smaller ones, descending more slowly, are deposited upon the larger and heavier fragments and crystals from the same eruption. We have a fine example of this stratification of submarine tufa in the centre of the South Pacific, lat. 22° 21′ S., long. 150° 17′ W. This specimen is entirely covered with peroxide of manganese, and at the base of the fragment we see the large crystals of hornblende and particles of magnetite. This lower layer is covered by a deposit in which these minerals and coarser grains are observed to pass gradually into a layer composed of small crystals of felspar, débris of pumice, and more or less fine material.

We do not propose to occupy ourselves here with the mode of formation of volcanic ashes, and with those of Krakatoa in particular. It will suffice to indicate that in the dust of a volcano we find all the characters supporting the interpretation which regards volcanic ashes as formed by the pulverisation of an igneous fluid mass in which float crystals already formed, and from which, when projected by gases, the pulverised vitreous particles undergo a rapid cooling and decrepitation during their passage through the atmosphere. It is not only the microscopic examination of these volcanic matters that leads us to this conclusion, but the prodigious quantity of ashes formed during the eruption of this volcano, which do not agree with the interpretation that regards these ashes as the result of a pulverisation of a rock already solidified in the crater. Indeed one cannot understand how, in two or three days, the immense quantity of ashes ejected from Krakatoa could be formed by this process, as, for instance, on the 26th August 1883 and in the May eruption, which was the prelude to that catastrophe.

Second Part.

The recent brilliant sunsets have been attributed to the presence in the atmosphere of minute particles of an extra-terrestrial origin, as well as to volcanic dust. This induces us to conclude this brief abstract of our observations by a description of the cosmic particles which we have found, along with volcanic ashes and pumice, in those regions of the deep sea far from land, where the sediment accumulates with extreme slowness.

In another memoir * we have pointed out the distribution of these particles on the floor of the ocean, and indicated the conclusions which we believe are justified by their relative abundance in the red clay areas of the Central Pacific.

It is known that the atmosphere holds in suspension an immense number of microscopic particles which are of organic and inorganic origin, and are either dust taken up by aerial currents from the ground or are extra-terrestrial bodies. A large number of scientific men, headed by Ehrenberg, Daubrée, Reichenbach, Nordenskiold, and Tissandier, have studied this interesting problem, and have brought forward many facts in support of the cosmic origin of some of the metallic particles found in atmospheric precipitations. It is certain that serious objections may be raised against the origin of a large number of so-called cosmic dusts.

In a great many cases it can be shown that these dusts are composed of the same minerals as the terrestrial rocks which are to be met with at short distances from the spot where the dust has been collected, and we can attribute a cosmic origin only to the metallic iron in these dusts. It is somewhat astonishing, however, that no trace is ever found in these dusts of meteoric silicates, although in a great many meteorites it might be said that the iron is only accidentally present, while the silicates predominate. On the other hand, having regard to the mineralogical composition of meteorites, it appears strange that the so-called cosmic dusts should present characters so variable, from the point of view of their mineralogical composition, in the different regions where they have been collected. It might also be objected that even the iron, nickel, and cobalt could come from volcanic rocks in decomposition in which these bodies are sometimes present, and this objection would seem quite natural, especially in our particular case, when we remember the numerous volcanic fragments in decomposition on the bottom of the sea. Again, according to numerous researches, native iron is found, although rarely, in various rocks and sedimentary layers of the globe. A reduction of the oxide of iron into metal might also be admitted under the influence of organic substances. It might still further be objected in opposition to the cosmic origin of the fine particles of native iron that they might be carried by aerial currents

* *Proc. Roy. Soc. Edin.*

from our furnaces, locomotives, the ashes of our grates, and in the case of the ocean, from steamers. All our materials of combustion furnish considerable quantities of iron dust, and it would not be astonishing to find that this, after having been transported by the winds, should again fall on the surface of the earth at great distances from its source.

Such are the objections which present themselves when it is proposed to pronounce upon the origin of particles which we are inclined to regard as cosmic, and of which we propose here to give a short description. We shall see that many of these doubts are at once removed by a statement of the circumstances under which cosmic spherules are found in deep sea deposits, and it will be found also that all the objections are disposed of when we show the association of metallic spherules with the most characteristic bodies of undoubted meteorites.

In the first place, the considerable distance from land at which we find cosmic particles in greatest abundance in deep sea deposits, eliminates at once objections which might be raised with respect to metallic particles found in the neighbourhood of inhabited countries. On the other hand, the form and character of the spherules of extra-terrestrial origin are essentially different from those collected near manufacturing centres. These magnetic spherules have never elongated necks or a cracked surface like those derived from furnaces with which we have carefully compared them. Neither are the magnetic spherules with a metallic centre comparable either in their form or structure to those particles of native iron which have been described in the eruptive rocks, especially in the basaltic rocks of the north of Ireland, of Iceland, &c.

Having referred to the objections, let us now see on what we must rely, in support of the hypothesis that many of the magnetic particles from the bottom of the sea which are specially abundant in those regions where the rate of accumulation of the deposit is exceedingly slow, are of cosmic origin. If we plunge a magnet into an oceanic deposit, specially a red clay from the central parts of the Pacific, we extract particles, some of which are magnetite from volcanic rocks, and to which vitreous matters are often attached; others again are quite isolated, and differ in most of their properties from the former. The latter are generally round,

measuring hardly 0·2 mm., generally they are smaller, their surface is quite covered with a brilliant black coating having all the properties of magnetic oxide of iron, often there may be noticed upon them cup-like depressions clearly marked. If we break down these spherules in an agate mortar, the brilliant black coating easily falls away and reveals white or grey metallic malleable nuclei, which may be beaten out by the pestle into thin lamellæ. This metallic centre, when treated with an acidulated solution of sulphate of copper, immediately assumes a coppery coat, thus showing that it consists of native iron. But there are some malleable metallic nuclei extracted from the spherules which do not give this reaction; they do not take the copper coating. Chemical reaction shows that they contain cobalt and nickel; very probably they constitute an alloy of iron and these two metals, such as is often found in meteorites, and whose presence

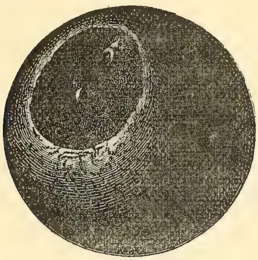


Fig. 2.—Black Spherule with Metallic Nucleus ($\frac{60}{1}$). This spherule covered with a coating of black shining magnetite represents the most frequent shape. The depression here shown is often found at the surface of these spherules. From 2375 fms. South Pacific.

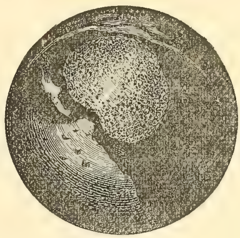


Fig. 3.—Black Spherule with Metallic Nucleus ($\frac{60}{1}$). The black external coating o magnetic oxide has been broken away to show the metallic centre, represented by the clear part at the centre. From 3150 fms. Atlantic.

in large quantities hinders the production of the coppery coating on the iron. G. Rose has shown that this coating of black oxide of iron is found on the periphery of meteorites of native iron, and its presence is readily understood when we admit their cosmic origin. Indeed, these meteoric particles of native iron in their transit through the air must undergo combustion, and, like small portions of iron from a smith's anvil, be transformed either entirely or at the surface only into magnetic oxide, and in this latter case the nucleus

is protected from further oxidation by the coating which thus covers it.

One may suppose that meteorites in their passage through the atmosphere break into numerous fragments, that incandescent particles of iron are thrown off all round them, and that these eventually fall to the surface of the globe as almost impalpable dust, in the form of magnetic oxide of iron more or less completely fused. The luminous trains of falling stars are probably due to the combustion of these innumerable particles resembling the sparks which fly from a ribbon of iron burnt in oxygen, or the particles of the same metal thrown off when striking a flint. It is easy to show that these particles in burning take a spherical form, and are surrounded by a layer of black magnetic oxide.

Among the magnetic grains found in the same conditions as these we have just described are other spherules, which we refer to the *chondres*, so that if the interpretation of a cosmic origin for the magnetic spherules with a metallic centre were not established in a manner absolutely beyond question, it almost becomes so when we take into account their association with the silicate spherules, of which we have now to speak. It will be seen by the microscopic details that these spherules have quite the constitution and structure of *chondres* so frequent in meteorites of the most ordinary type, and on the other hand they have never been found, as far as we know, in rocks of a terrestrial origin; in short, the presence of these spherules in the deep sea deposits, and their association with the metallic spherules, is a matter of prime importance. Let us see how we distinguish these silicate spherules, and the points upon which we rely in attributing to them a cosmic origin.

Among the fragments attracted by the magnet in deep sea deposits we distinguish granules slightly larger than the spherules with the shining black coating above described. These are yellowish-brown, with a bronze-like lustre, and under the microscope, it is noticed that the surface, instead of being quite smooth, is grooved by thin lamellæ. In size they never exceed a millimetre, generally they are about 0·5 mm. in diameter; they are never perfect spheres, as in the case of the black spherules with a metallic centre; and sometimes a depression more or less marked

is to be observed in the periphery. When examined by the microscope we observe that the lamellæ which compose them are applied the one against the other, and have a radial eccentric disposition. It is the leafy radial structure (*radialblättrig*), like that of the *chondres* of bronzite, which predominates in our preparations. We have observed much less rarely the serial structure of the chondres with olivine, and indeed there is some doubt about the indications of this last type of structure. Fig. 4 shows the characters and texture of one of these spherules magnified 25 diameters. On account of their small dimensions, as well as of their friability due to their lamellar structure, it is difficult to polish one of these spherules, and we have been obliged to study them with reflected light, or to limit our observations to the study of the broken fragments.

These spherules break up following the lamellæ, which latter are seen to be extremely fine and perfectly transparent. In rotating

Fig. 4.—Spherule of bronzite ($\frac{25}{1}$) from 3500 fathoms in the Central South Pacific, showing many of the peculiarities belonging to chondres of bronzite or enstatite.

between crossed nicols they have the extinctions of the rhombic system, and in making use of the condenser it is seen that they have one optic axis. It is observed also that when several of these lamellæ are attached, they extinguish exactly at the same time, so that everything induces us to believe that they form a single individual.

In studying these transparent and very thin fragments with the aid of a high magnifying power, it is observed that they are dotted

with brown-black inclusions, disposed with a certain symmetry, and showing somewhat regular contours; we refer these inclusions to magnetic iron, and their presence explains how these spherules of bronzite are extracted by the magnet. We would observe, however, that they are not so strongly magnetic as those with a metallic nucleus.

We designate them under the name of bronzite rather than of enstatite, because of the somewhat deep tint which they present; they are insoluble in hydrochloric acid. Owing to the small quantity of substance at our disposal, we were obliged to limit ourselves to a qualitative analysis. We have found in them silica, magnesia, and iron.

We have limited our remarks at this time to these succinct details, but we believe that we have said enough to show that these spherules in their essential characters are related to the chondres of meteorites, and have the same mode of formation. In conclusion, we may state that when the coating of manganese depositions, which surround sharks' teeth, ear-bones of cetaceans and other nuclei, is broken off and pounded in a mortar to fine dust, and the magnetic particles then extracted by means of a magnet, we find these latter to be composed of silicate spherules, spherules with a metallic centre, and magnetic iron, in all respects similar to those found in the deposits in which the nodules were embedded.

We have recently examined the dust collected by melting the snow at the Observatory on Ben Nevis, in order to see whether, in that elevated and isolated region, we should be able to find volcanic ashes or cosmic spherules analogous to those we have described. This atmospheric dust, which we have examined microscopically, has not shown any particles which could with certainty be regarded as identical with those substances which are the subject of this paper. Particles of coal, fragments of ashes, and grains of quartz predominated. Besides these, there were fragments of calcite, augite, mica, and grains of rock of all forms and of variable dimensions. These were associated with fibres of cotton, of vegetables, splinters of limonite and of tin—in short, everything indicating a terrestrial origin.

In order to give an idea of the facility with which the winds

may carry these matters even to the summit of the mountain, we may add that Mr Omond has sent to us fragments of crystalline rocks, some having a diameter of two centimetres, which, he states, were collected on the surface of the snow at the summit after the storm of 26th January 1884.

Arrangements are being made to collect the dust at the top of Ben Nevis during calms with great care.

3. On the Nomenclature, Origin, and Distribution of Deep-Sea Deposits. By John Murray and A. Renard. Communicated by John Murray.

Introduction.—The sea is unquestionably the most powerful dynamic agent on the surface of the globe, and its effects are deeply imprinted on the external crust of our planet; but among the sedimentary deposits which are attributed to its action, and among the effects which it has wrought on the surface features of the earth, the attention of geologists has, till within quite recent times, been principally directed to the phenomena which take place in the immediate vicinity of the land. It is incontestable that the action of the sea along coasts and in shallow water has played the largest part in the formation and accumulation of those marine sediments which, so far as we can observe, form the principal strata of the solid crust of the globe; and it has been from an attentive study of the phenomena which take place along the shores of modern seas that we have been able to reconstruct in some degree the conditions under which the marine deposits of ancient times were laid down.

Attention has been paid only in a very limited degree to deposits of the same order and, for the greater part, of the same origin, which differ from the sands and gravels of the shores and shallow waters only by a lesser size of the grains, and by the fact that they are laid down at a greater distance from the land and in deeper water. And still less attention has been paid to those true deep-sea deposits which are only known through systematic submarine investigations. One might well ask what deposits are now taking place, or have in past ages taken place, at the

bottom of the great oceans at points far removed from land, and in regions where the erosive and transporting action of water has little or no influence. Without denying that the action of the tidal waves can, under certain special conditions, exert an erosive and transporting power at great depths in the ocean, especially on submerged peaks and barriers, it is none the less certain that these are exceptional cases, and that the action of waves is almost exclusively confined to the coasts of emerged land. There are in the Pacific immense stretches of thousands of miles where we do not encounter any land, and in the Atlantic we have similar conditions. What takes place in these vast regions where the waves exercise no mechanic action on any solid object? We are about to answer this question by reference to the facts which an examination of deep-sea sediments has furnished.

A study of the sediments recently collected in the deep sea shows that their nature and mode of formation, as well as their geographical and bathymetrical distribution, permit deductions to be made which have a great and increasing importance from a geological point of view. In making known the composition of these deposits and their distribution, the first outlines of a geological map of the bottom of the ocean will be sketched.

This is not the place to give a detailed history of the various contributions to our knowledge of the terrigenous deposits in deep water near land, or of those true deep-sea deposits far removed from land, which may be said to form the special subject of this communication. From the time of the first expeditions, undertaken with a view of ascertaining the depth of the ocean, small quantities of mud have been collected by the sounding lead and briefly described. We may recall in this connection the experiments of Ross and the observations of Hooker and Maury. These investigations, made with more or less imperfect appliances, immediately fixed the attention, without, however, giving sufficient information on which to establish any general conclusions as to the nature of the deposits or their distribution in the depths of the sea.

When systematic soundings were undertaken with a view of establishing telegraphic communication between Europe and America, the attention of many distinguished men was directed to the importance, in a biological and geological sense, of the specimens of

mud brought up from great depths. The observations of Wallich, Huxley, Agassiz, Baily, Pourtalès, Carpenter, Thomson, and many others, while not neglecting mineralogical and chemical composition, deal with this only in a subordinate manner. The small quantities of each specimen at their command, and the limited areas from which they were collected, did not permit the establishment of any general laws as to their composition or geographical and bathymetrical distribution. These early researches, however, directed attention to the geological importance of deep-sea deposits, and prepared the way for the expeditions organised with the special object of a scientific exploration of the great ocean basins.

The expedition of the "Challenger" takes the first rank in these investigations. During that expedition a large amount of material was collected and brought to England for fuller study under the charge of Mr Murray, who has in several preliminary papers pointed out the composition and varieties of deposits which are now forming over the floor of the great oceans. In order to arrive at results as general as possible, it was resolved to investigate the subject from the biological, mineralogical, and chemical points of view, and M. Renard was associated with Mr Murray in the work. In addition to the valuable collections and observations made by the "Challenger," we have had for examination material collected by other British ships, such as the "Porcupine," "Bulldog," "Valorous," "Nassau," "Swallow," "Dove;" and, through Professor Mohn, by the Norwegian North Atlantic Expedition. Again, through the liberality of the United States Coast Survey and Mr A. Agassiz, the material amassed in the splendid series of soundings taken by the American ships "Tuscarora," "Blake," and "Gettysburg," were placed in our hands. The results at which we have arrived may therefore be said to have been derived from a study of all the important available material.

The work connected with the examination and description of these large collections is not yet completed, but it is sufficiently advanced to permit some general conclusions to be drawn, which appear to be of considerable importance. In addition to descriptions and results, we shall briefly state the methods we have

adopted in the study. All the details of our research will be given in the Report on the Deep-Sea Deposits in the "Challenger" series, which will be accompanied by charts indicating the distribution, plates showing the principal types of deposits as seen by the microscope, and numerous analyses giving the chemical composition and its relation to the mineralogical composition. The description of each sediment will be accompanied by an enumeration of the organisms dredged with the sample, so as to furnish all the biological and mineralogical information which we possess on deep-sea deposits, and finally, we shall endeavour to establish general conclusions which can only be indicated at present.

Before entering on the subject, we believe it right to point out the difficulties which necessarily accompany such a research as the one now under consideration, difficulties which arise often in part from the small quantity of the substance at our disposal, but also from the very nature of the deposit. Since we have endeavoured to determine, with great exactitude, the composition of the deposit at any given point, we have, whenever possible, taken the sample collected in the sounding tube. That procured by the trawl or dredge, although usually much larger, is not considered so satisfactory on account of the washing and sorting to which the deposit has been subjected while being hauled through a great depth of water. We have, however, always examined carefully the contents of these instruments, although we do not think the material gives such a just idea of the deposit as the sample collected by the sounding tube. The material collected by the last named instrument has been taken as the basis of our investigations, although the small quantity often gives to it an inherent difficulty. It was the small quantity of substance collected by the sounding tube in early expeditions which prevented the first observers from arriving at any definite results; but when such small samples are supplemented by occasional large hauls from the dredge or trawl, they become much more valuable and indicative of the nature of the deposit as a whole. Not only the scantiness of the material, but the small size of the grains, which in most instances make up deep-sea deposits, render the determinations difficult. In spite of the improvements recently effected in the microscopical examination of minerals, it is impossible to apply all the optical resources of the

instrument to the determination of the species of extremely fine, loose, and fractured particles. Again, the examination of these deposits is rendered difficult by the presence of a large quantity of amorphous mineral matter, and of shells, skeletons, and minute particles of organic origin. It is also to be observed that we have not to deal with pure and unaltered mineral fragments, but with particles upon which the chemical action of the sea has wrought great changes, and more or less destroyed their distinctive characters.

What still further complicates these researches is the endeavour to discover the origin of the heterogeneous materials which make up the deposits. These have been subjected to the influence of a great number of agents of some of which our knowledge is to a great extent still in its infancy. We must take into account a large number of agents and processes, such as ocean currents; the distribution of temperature in the water at the surface and at the bottom; the distribution of organisms as dependent on temperature and specific gravity of the water; the influence of aerial currents; the carrying power of rivers; the limit of transport by waves; the eruptions of aerial and submarine volcanoes; the effect of glaciers in transporting mineral particles, and, when melting, influencing the specific gravity of the water, which in turn affects the animal and plant life of the surface. It is necessary to study the chemical reactions which take place in great depths; in short, to call to our aid all the assistance which the physical and biological sciences can furnish. It will thus be understood that the task, like all first attempts in a new field, is one of exceptional difficulty, and demands continued effort to carry it to a successful issue.

In presenting a short *resumé* of our methods, of the nomenclature we have adopted, and of the investigation into the origin of the deposits in the deep sea and deeper parts of the littoral zones, we offer it as a sketch of our research, prepared to modify the arrangements in any way which an intelligent criticism may suggest.

Before proceeding to a description of methods and of the varieties of deposits, with their distribution in modern oceans, we will briefly enumerate the materials which our examination has shown take part in the formation of these deposits, state the origin of these

materials, and the agents concerned in their deposition, distribution, and modification.

Materials.—The materials which unite to form the deposits which we have to describe may be divided into two groups, viewed in relation to their origin, viz., mineral and organic.

The mineral particles carried into the ocean have a different form and size, according to the agents which have been concerned in their transport. Generally speaking, their size diminishes with distance from the coast, but here we limit our remarks to the mineralogical character of the particles. We find isolated fragments of rocks and minerals coming from the crystalline and schisto-crystalline series, and from the clastic and sedimentary formations ; according to the nature of the nearest coasts they belong to granite, diorite, diabase, porphyry, &c. ; crystalline schists, ancient limestones, and the sedimentary rocks of all geological ages, with the minerals which come from their disintegration, such as quartz, monoclinic and triclinic felspars, hornblende, augite, rhombic pyroxene, olivine, muscovite, biotite, titanic and magnetic iron, tourmaline, garnet, epidote, and other secondary minerals. The trituration and decomposition of these rocks and minerals give rise to materials more or less amorphous and without distinctive characters, but the origin of which is indicated by association with the rocks and minerals just mentioned.

Although the débris of continental land to which we have just referred plays the most important rôle in the immediate vicinity of shores, yet our researches show beyond doubt that when we pass out towards the central parts of the great ocean basins, the débris of continental rocks gradually disappears from the deposits, and its place is taken by materials derived from modern volcanic rocks, such as basalts, trachytes, augite-andesites, and vitreous varieties of these lithological families, for instance, pumice and loose incoherent volcanic particles of recent eruptions, with their characteristic minerals. All these mineral substances being usually extremely fine or areolar in structure, are easily attacked by the sea water at the place where they are deposited. This chemical action brings about an alteration of the minerals and vitreous fragments, which soon passes into complete decomposition, and in special circumstances gives rise to the formation of secondary products. In some

places the bottom of the sea is covered with deposits due to this chemical action, principal among which is clayey matter, associated with which there are often concretions composed of manganese and iron. In other regions the reactions which result in the formation of argillaceous matter from volcanic products give rise also to the formation of zeolites.

Among other products arising from chemical action, probably combined with the activity of organic matter, may be mentioned the formation of glauconite and phosphatic nodules, with, in some rare and doubtful examples, the deposition of silica. The decomposition of the tissues, shells, and skeletons of organisms add small quantities of iron, fluorine, and phosphoric acid to the inorganic constituents of the deep-sea deposits.

Finally, we must mention extra-terrestrial substances in the form of cosmic dust.

We now pass to the consideration of the rôle played by organisms in the formation of marine deposits. Organisms living at the surface of the ocean, along the coasts, and at the bottom of the sea, are continually extracting the lime, magnesia, and silica held in solution in sea water. The shells and skeletons of these, after the death of the animals and plants, accumulate at the bottom and give rise to calcareous and siliceous deposits. The calcareous deposits are made up of the remains of coccospheres, rhabdospheres, pelagic and deep-sea Foraminifera, pelagic and deep-sea Molluscs, Corals, Alcyonarians, Polyzoa, Echinoderms, Annelids, Fish, and other organisms. The siliceous deposits are formed principally of frustules of Diatoms, skeletons of Radiolarians, and spicules of Sponges.

While the minute pelagic and deep-sea organisms above mentioned play by far the most important part in the formation of deep-sea deposits, the influence of vertebrates is recognisable only in a very slight degree in some special regions by the presence of large numbers of sharks' teeth, and the ear bones and a few other bones of whales. The otoliths of fish are usually present in the deposits, but, with the exception of two vertebræ and a scapula, no other bones of fish have been detected in the large amount of material we have examined.

Agents.—Having passed in review the various materials which

go to the formation of deposits in the deep water immediately surrounding the land and in the truly oceanic areas, attention must now be directed to the agents which are concerned in the transport and distribution of these, and to the sphere of their action. The relations existing between the organic and inorganic elements of deposits to which we have just referred, and the laws which determine their distribution, will be pointed out at the same time.

The fluids which envelope the solid crust of the globe are incessantly at work disintegrating the materials of the land, which, becoming loose and transportable, are carried away sometimes by the atmosphere, sometimes by water, to lower regions, and are eventually borne to the ocean in the form of solid particles or as matter in solution. The atmosphere when agitated, after having broken up the solid rock, transports the particles from the continents, and in some regions carries them far out to sea, where they form an appreciable portion of the deposit; as, for instance, off the west coast of North Africa and the south-west coast of Australia. Again, in times of volcanic eruptions, the dust and scoria which are shot into the air, are carried immense distances by winds and atmospheric currents, and no small portion eventually falls into the sea.

Water is, however, the most powerful agent concerned in the formation and distribution of marine sediments. Running water corrodes the surface of the land, and carries the triturated fragments down into the ocean. The waters of the ocean, in the form of waves and tides, attack the coasts and distribute the débris at a lower level. Independently of the action of waves, there exist along most coasts currents, more or less constant, which have an effect in removing sand, gravel, and pebbles further from their origin. Generally, terrestrial matters appear to be distributed by these means to a distance of one or two hundred miles from the coast. Waves and currents probably have no erosive or transporting power at depths greater than 200 or 300 fathoms, and even at such depths it is necessary that there should be some peculiar configuration of the bottom in order that the agitated water may produce any mechanical effect. However, it is not improbable that, by a peculiar configuration of the bottom and ridges among oceanic islands, the deposit on a ridge may be disturbed by the tidal wave even at 1000 fathoms; and this may be the cause of the hard

ground sometime met with in such positions. By observations off the coast of France, it has been shown that fine mud is at times disturbed at a depth of 150 fathoms; but, while admitting that this is the case on exposed coasts, the majority of observations indicate that beyond 100 fathoms it is an oscillation of the water, rather than a movement capable of exerting any geological action, which concerns us in this connection.

Although the great oceanic currents have no direct influence upon the bottom, yet they have a very important indirect effect on deposits, because the organisms which live in the warm equatorial currents form a very large part of the sediment being deposited there, and this in consequence differs greatly from the deposits forming in regions where the surface-water is colder. In the same way a high or low specific gravity of the surface-water has an important bearing on the animal and vegetable life of the ocean, and this in its turn affects the character of the deposits.

The thermometric observations of the "Challenger" show that a slow movement of cold water must take place in all the greater depths of the ocean from the poles, but particularly from the southern pole, towards the equator. It could be shown from many lines of argument that this extremely slow massive movement of the water can have no direct influence on the distribution of marine sediments.

Glaciers which eventually become icebergs, that are carried far out to sea by currents, transport detrital matter from the land to the ocean, and thus modify in the Arctic and Antarctic regions the deposits taking place in the regions affected by them. The detritus from icebergs in the Atlantic can be traced as far south as latitude 36° off the American coast, and in the southern hemisphere as far north as latitude 40°.

The fact that sea water retains fine matter in suspension for a much shorter time than fresh water should be referred to here as having an important influence in limiting the distribution of fine argillaceous and other materials borne down to the sea by rivers, thus giving a distinctive character to deposits forming near land.

We have pointed out the influence of temperature and salinity upon the distribution of the surface organisms whose skeletons form a large part of some oceanic deposits, and may state also that the bathymetrical distribution of calcareous organisms is influenced by

the chemical action of sea water. We will return to these influences presently when describing the distribution of the various kinds of deposits and their reciprocal relations, especially in those regions of the deep sea far removed from the mechanical action of rivers, waves, and superficial currents. The action of life as a geological agent has been indicated under the heading *Materials.*

Methods.—We give here an example showing the order followed in describing the deposits examined.

Station 338; lat. 21° 15′ S., long. 14° 2′ W.; 21st March 1876; surface temperature 76°·5, bottom temperature 36°·5, depth 1990 fathoms.

GLOBIGERINA OOZE, white with slight rosy tinge when wet; granular, homogeneous, and very slightly coherent when dry; resembles chalk.

i. *Carbonate of Calcium*, 90·38 per cent., consists of pelagic Foraminifera (80 per cent.); coccoliths and rhabdoliths (9 per cent.); Miliolas, Discorbinas, and other Foraminifera, Ostracode valves, fragments of Echini spines, and one or two small fragments of Pteropods (1·38 per cent.).

ii. *Residue*, 9·62 per cent., reddish-brown; consists of

1. *Minerals* [1·62] m. di. 0·45 mm., fragments of felspar, hornblende, magnetite, magnetic spherules, a few small grains of manganese, and pumice.
2. *Siliceous Organisms* [1·00], Radiolarians, spicules of Sponges, and imperfect casts of Foraminifera.
3. *Fine Washings* [7·00], Argillaceous matter with small mineral particles and fragments of pumice and siliceous organisms.

The description of the deposits has been made upon this plan which was adopted after many trials and much consideration. This is not the place to give the reasons which have guided us in adopting this mode of description, or to give in detail the methods that we have systematically employed for all the sediments which we are engaged in describing. These will be fully given in the introduction to our "Challenger" Report. We limit ourselves here to explaining the meanings and arrangement of terms and abbreviations, so that the method may be understood and made available for others.

The description commences by indicating the kind of deposit (red clay, blue mud, globigerina ooze, &c.), with the microscopic characters of the deposit, when wet or dry.

We have always endeavoured to give a complete chemical analysis of the deposit, but when it was impossible to do this we have always determined the amount of *Carbonate of Calcium.* This determination was generally made by estimating the carbonic acid.

We usually took a gramme of a mean sample of the substance for this purpose, using weak and cold hydrochloric acid. However, as the deposits often contain carbonates of magnesia and iron as well, the results calculated by associating the carbonic acid with the lime are not perfectly exact, but these carbonates of magnesia and iron are almost always in very small proportion, and the process is, we think, sufficiently accurate, for, owing to the sorting of the elements which goes on during collection and carriage, no two samples from the same station give exactly the same percentage. The number which follows the words "*Carbonate of Calcium*" indicates the percentage of $CaCO_3$; we then give the general designations of the principal calcareous organisms in the deposit.

The part insoluble in the hydrochloric acid, after the determination of the carbonic acid, is designated in our descriptions "*Residue.*" The number placed after this word indicates its percentage in the deposit; then follow the colour and principal physical properties. This residue is washed and submitted to decantations, which separate the several constituents according to their density; these form three groups—(1) *Minerals*, (2) *Siliceous Organisms*, (3) *Fine Washings.*

1. *Minerals.*—The number within brackets indicates the percentage of particular minerals and fragments of rocks. This number is the result of an approximate evaluation, of which we will give the basis in our report. As it is important to determine the dimensions of the grains of minerals which constitute the deposit, we give, after the contraction *m. di.*, their mean diameter in millimetres. We give next the form of the grains, if they are rounded or angular, &c.; then the enumeration of the species of minerals and rocks. In this enumeration we have placed the minerals in the order of the importance of the rôle which they play in the deposit. The specific determinations have been made with the mineralogical microscope in parallel or convergent polarised light.

2. *Siliceous Organisms.*—The number between brackets indicates the percentage of siliceous organic remains; we obtain it in the same manner as that placed after the word *Minerals.* The siliceous organisms and their fragments are examined with the microscope and determined. We have also placed under this heading the glauconitic casts of the Foraminifera and other calcareous organisms.

3. *Fine Washings.*—We designate by this name the particles which, resting in suspension, pass with the first decantation. They are about 0·05 mm. or less in diameter. We have been unable to arrange this microscopic matter under the category of *Minerals*, for, owing to its minute and fragmentary nature, it is impossible to determine the species. We have always found that the *Fine Washings* increase in quantity as the deposit passes to a clay, and it is from this point of view that the subdivision has its *raison d'être.* We often designate the lightest particles by the name argillaceous matter, but usually there are associated with this very small particles of indeterminable minerals and fragments of siliceous organisms. The number within brackets which follows the words *Fine Washings* is obtained in the same manner as those placed after *Minerals* and *Siliceous Organisms.*

These few words will suffice to render the descriptions intelligible. Greater details will be given, as already stated, in the "Challenger" Report. It may be added that in the majority of cases we have solidified the sediments and formed them into thin slides for microscopic examination, and that at all times the examination by transmitted light has been carried on at the same time as the examination by reflected light. Each description is followed by notes upon the dredging or sounding, upon the animals collected, and a discussion of the analysis whenever a complete analysis has been made, which is always the case with typical samples of the deposits.

Kinds of Deposits.—We now proceed to the description of the various types of deposits into which it is proposed to divide the marine formations that are now taking place in the deeper water of the various oceans and seas. We will speak first of those which are met with in the deeper water of inland seas, and around the coasts of continents and islands, and afterwards of those which are found in the abysmal regions of the great oceans. Those coast formations which are being laid down on the shores, or in very shallow water, and which have been somewhat carefully described previous to the recent deep-sea explorations, are here neglected.

A study of the collections made by the "Challenger" and other expeditions show—

(1) That in the deeper water around continents and islands

which are neither of volcanic nor coral origin, the sediments are essentially composed of a mixture of sandy and amorphous matter, with a few remains of surface organisms, to which we give the name of *muds*, and which may be distinguished macroscopically by their colour. We distinguish them by the names, *blue*, *red*, and *green muds*.

(2) Around volcanic islands the deposits are chiefly composed of mineral fragments derived from the decomposition of volcanic rocks. These, according to the size of the grains, are called *volcanic muds or sands*.

(3) Near coral islands and along shores fringed by coral reefs, the deposits are calcareous, derived chiefly from the disintegration of the neighbouring reefs, but they receive large additions from shells and skeletons of pelagic organisms, as well as from animals living at the bottom. These are named, according to circumstances, *coral or coralline muds and sands.*

Let us now see what are the chief characteristics of each of these deposits.

Blue mud is the most extensive deposit now forming around the great continents and continental islands, and in all enclosed or partially enclosed seas. It is characterised by a slaty colour which passes in most cases into a thin layer of a reddish colour at the upper surface. These deposits are coloured blue by organic matter in a state of decomposition, and frequently give off an odour of sulphuretted hydrogen. When dried, a blue mud is greyish in colour, and rarely or never has the plasticity and compactness of a true clay. It is finely granular, and occasionally contains fragments of rocks 2 centimetres in diameter; generally, however, the minerals, which are derived from the continents, and are found mixed up with the muddy matter in these deposits, have a diameter of 0·5 mm. and less. Quartz particles, often rounded, play the principal part, next come mica, felspar, augite, hornblende, and all the mineral species which come from the disintegration of the neighbouring lands, or the lands traversed by rivers which enter the sea near the place where the specimens have been collected. These minerals make up the principal and characteristic portion of blue muds, sometimes forming 80 per cent. of the whole deposit. Glauconite, though generally present, is never abundant in blue

muds. The remains of calcareous organisms are at times quite absent, but occasionally they form over 50 per cent. The latter is the case when the specimen is taken at a considerable distance from the coast and at a moderate depth. These calcareous fragments consist of bottom-living and pelagic Foraminifera, Molluscs, Polyzoa, Serpulæ, Echinoderms, Alcyonarian-spicules, Corals, &c. The remains of Diatoms and Radiolarians are usually present. Generally speaking, as we approach the shore the pelagic organisms disappear; and on the contrary, as we proceed seawards, the size of the mineral grains diminishes, and the remains of shore and coast organisms give place to pelagic ones, till finally a blue mud passes into a true deep-sea deposit. In those regions of the ocean affected with floating ice the colour of these deposits becomes gray rather than blue at great distances from land, and is further modified by the presence of a greater or less abundance of glaciated blocks and fragments of quartz.

Green Muds and Sands.—As regards their origin, composition, and distribution near the shores of continental land, these muds and sands resemble the blue muds. They are largely composed of argillaceous matter and mineral particles of the same size and nature as in the blue muds. Their chief characteristic is the presence of a considerable quantity of glauconitic grains, either isolated or united into concretions. In the latter case the grains are cemented together by a brown argillaceous matter, and include, besides quartz, felspars, phosphate of lime, and other minerals, more or less altered. The Foraminifera and fragments of Echinoderms and other organisms in these muds are frequently filled with glauconitic substance, and beautiful casts of these organisms remain after treatment with weak acid. At times there are few calcareous organisms in these deposits, and at other times the remains of Diatoms and Radiolarians are abundant. When these muds are dried they become earthy and of a grey-green colour. They frequently give out a sulphuretted hydrogen odour. The green colour appears sometimes to be due to the presence of organic matter, probably of vegetable origin, and to the reduction of peroxide of iron to protoxide under its influence. The *green sands* differ from the muds only in the comparative absence of the argillaceous and other amorphous matter, and by the more important part played by

the grains of glauconite, which chiefly give the green colour to these sands.

Red Muds.—In some localities, as for instance off the Brazilian coast of America, the deposits differ from blue muds by the large quantity of ochreous matter brought down by the rivers and deposited along the coast. The ferruginous particles when mixed up with the argillaceous matter give the whole deposit a reddish colour. These deposits, rich in iron in the state of limonite, do not appear to contain any traces of glauconite, and have relatively few remains of siliceous organisms.

Volcanic Muds and Sands.—The muds and sands around volcanic islands are black or grey; when dried they are rarely coherent. The mineral particles are generally fragmentary, and consist of lapilli of the basic and acid series of modern volcanic rocks, which are scoriaceous or compact, vitreous or crystalline, and usually present traces of alteration. The minerals are sometimes isolated, sometimes surrounded by their matrix, and consist principally of plagioclases, sanidine, amphibole, pyroxene, biotite, olivine, and magnetic iron; the size of the particles diminishes with distance from the shore, but the mean diameter is generally 0·5 mm. Glauconite does not appear to be present in these deposits, and quartz is also very rare or absent. The fragments of shells and rocks are frequently covered with a coating of peroxide of manganese. Shells of calcareous organisms are often present in great abundance, and render the deposit of a lighter colour. The remains of Diatoms and Radiolarians are usually present.

Coral Muds.—These muds frequently contain as much as 95 per cent. of carbonate of lime, which consists of fragments of Corals, calcareous Algæ, Foraminifera, Serpulæ, Molluscs, and remains of other lime-secreting organisms. There is a large amount of amorphous calcareous matter, which gives the deposit a sticky and chalky character. The particles may be of all sizes according to the distance from the reefs, the mean diameter being 1 to 2 mm., but occasionally there are large blocks of coral and large calcareous concretions; the particles are white and red. Remains of siliceous organisms seldom make up over 2 or 3 per cent. of a typical coral mud. The *residue* consists usually of a small amount of argillaceous matter, with a few fragments of felspar and other volcanic minerals; but off

barrier and fringing reefs facing continents we may have a great variety of rocks and minerals. Beyond a depth of 1000 fathoms off coral islands the débris of the reefs begins to diminish, and the remains of pelagic organisms to increase; the deposit becomes more argillaceous, of a reddish or rose colour, and gradually passes into a Globigerina ooze or a red clay. *Coral Sands* contain much less amorphous matter than coral muds, but in other respects they are similar, the sands being usually found nearer the reefs and in shallower water than the muds, except inside lagoons. In some regions the remains of calcareous algæ predominate, and in these cases the name *coralline mud or sand* is employed to point out the distinction.

Such is a rapid view of the deposits found in the deeper waters of the littoral zones, where the débris from the neighbouring land plays the most important part in the formation of muds and sands. When, however, we pass beyond a distance of about 200 miles from land, we find that the deposits are characterised by the great abundance of fragmentary volcanic materials which have usually undergone great alteration, and by the enormous abundance of the shells and skeletons of minute pelagic organisms which have fallen to the bottom from the surface waters. These true deep-sea deposits may be divided into those in which the organic elements predominate, and those in which the mineral constituents play the chief part. We commence with the former.

Globigerina Ooze.—We designate by this name all those truly pelagic deposits containing over 40 per cent. of carbonate of lime, which consists principally of the dead shells of pelagic Foraminifera—*Globigerina*, *Orbulina*, *Pulvinulina*, *Pullenia*, *Sphæroidina*, &c. In some localities this deposit contains 95 per cent. of carbonate of lime. The colour is milky white, yellow, brown, or rose, the varieties of colour depending principally on the relative abundance in the deposit of the oxides of iron and manganese. This ooze is fine grained; in the tropics some of the Foraminifera shells are macroscopic. When dried it is pulverulent. Analyses show that the sediment contains, in addition to carbonate of lime, phosphate and sulphate of lime, carbonate of magnesia, oxides of iron and manganese, and argillaceous matters. The *residue* is of a reddish-brown

tinge. Lapilli, pumice, and glassy fragments, often altered into palagonite, seem always to be present, and are frequently very abundant. The mineral particles are generally angular, and rarely exceed 0·08 mm. in diameter; monoclinic and triclinic felspars, augite, olivine, hornblende, and magnetite are the most frequent. When quartz is present, it is in the form of minute, rounded, probably wind-borne grains, often partially covered with oxide of iron. More rarely we have white and black mica, bronzite, actinolite, chromite, glauconite, and cosmic dust. Siliceous organisms are probably never absent, sometimes forming 20 per cent. of the deposit, at other times they are only recognisable after careful microscopic examination. In some regions the frustules of Diatoms predominate, in others the skeletons of Radiolarians.

The *fine washings*, viewed with the microscope, are not homogeneous. The greater part consists of argillaceous matter coloured by the oxides of iron and manganese. Mixed with this, we distinguish fragments of minerals with a diameter less than 0·05 mm., and minute particles of pumice can nearly always be detected. Fragments of Radiolarians, Diatoms, and siliceous spicules can always be recognised, and are sometimes very abundant.

Pteropod Ooze.—This deposit differs in no way from a Globigerina ooze except in the presence of a greater number and variety of pelagic organisms, and especially in the presence of Pteropod and Heteropod shells, such as *Diacria*, *Atlanta*, *Styliola*, *Carinaria*, &c., &c. The shells of the more delicate species of pelagic Foraminifera and young shells are also more abundant in these deposits than in a Globigerina ooze. It must be remembered that the name "Pteropod ooze" is not intended to indicate that the deposit is chiefly composed of the shells of these molluscs, but, as their presence in a deposit is characteristic and has an important bearing on geographical and bathymetrical distribution, we think it desirable to emphasise the presence of these shells in any great abundance. It may here be pointed out that there is a very considerable difference between a Globigerina ooze, or a Pteropod ooze situated near continental shores, and deposits bearing the same names situated towards the centres of oceanic areas, both with respect to mineral particles and remains of organisms.

Diatom Ooze.—This ooze is of a pale straw colour, and is composed

principally of the frustules of Diatoms. When dry it is a dirty white siliceous flour, soft to the touch, taking the impression of the fingers, and contains gritty particles which can be recognised by the touch. It contains on an average about 25 per cent. of carbonate of lime, which exists in the deposit in the form of small *Globigerina* shells, fragments of Echinoderms and other organisms. The *residue* is pale white and slightly plastic; minerals and fragments of rocks are in some cases abundant; these are volcanic, or, more frequently, fragments and minerals coming from continental rocks and transported by glaciers. The *fine washings* consist essentially of particles of Diatoms along with argillaceous and other amorphous matter. We estimate that the frustules of Diatoms and skeletons of siliceous organisms make up more than 50 per cent. of this deposit.

Radiolarian Ooze.—It was stated, when describing a Globigerina ooze, that Radiolarians were seldom, if ever, completely absent from marine deposits. In some regions they make up a considerable portion of a Globigerina ooze, and are also found in Diatom ooze and in the terrigenous deposits of the deeper water surrounding, however, the land. In some regions of the Pacific, the skeletons of these organisms make up the principal part of the deposits, and to these we have given the name "Radiolarian ooze." The colour is reddish or deep brown, due to the presence of the oxides of iron and manganese. The *mineral particles* consist of fragments of pumice, lapilli, and volcanic minerals, rarely exceeding 0·07 mm. in diameter. There is not a trace of carbonate of lime in the form of shells in some samples of Radiolarian ooze, but other specimens contain 20 per cent. of carbonate of lime derived from the shells of pelagic Foraminifera. The clayey matter and mineral particles in this ooze are the same as those found in the red clays, which we will now proceed to describe.

Red Clay.—Of all the deep-sea deposits this is the one which is distributed over the largest areas in the modern oceans. It might be said that it exists everywhere in the abysmal regions of the ocean basins, for the *residue* in the organic deposits which have been described under the names Globigerina, Pteropod, and Radiolarian ooze, is nothing else than the red clay. However, this deposit only appears in its characteristic form in those areas where the terrigenous minerals and calcareous and siliceous organisms disappear to

a greater or less extent from the bottom. It is in the central regions of the Pacific that we meet with the typical examples. Like other marine deposits, this one passes laterally, according to position and depth, into the adjacent kinds of deep-sea ooze or mud.

The argillaceous matters are of a more or less deep brown tint from the presence of the oxides of iron and manganese. In the typical examples no mineralogical species can be distinguished by the naked eye, for the grains are exceedingly fine and of nearly uniform dimensions, rarely exceeding 0·05 mm. in diameter. It is plastic and greasy to the touch; when dried it coagulates into lumps so coherent that considerable force must be employed to break them. It gives the brilliant streak of clay, and breaks down in water. The pyrognostic properties show that we are not dealing with a pure clay, for it fuses easily before the blow-pipe into a magnetic bead.

Under the term red clay are comprised those deposits in which the characters of clay are not well pronounced, but which are mainly composed of minute particles of pumice and other volcanic material which, owing to their relatively recent deposition, have not undergone great alteration. If we calculate the analyses of red clay it will be seen, moreover, that the silicate of alumina present as clay ($2SiO_2,Al_2O_3 + 2H_2O$) comprises only a relatively small portion of the sediment, the calculation shows always an excess of free silica, which is attributed chiefly to the presence of siliceous organisms.

Microscopic examination shows that a red clay consists of argillaceous matter, minute mineral particles, and fragments of siliceous organisms; in a word, it is in all respects identical with the *residue* of the organic oozes. The mineral particles are for the greater part of volcanic origin, except in those cases where continental matters are transported by floating ice, or where the sand of deserts has been carried to great distances by winds. These volcanic minerals are the same constituent minerals of modern eruptive rocks, enumerated in the description of volcanic muds and sands; in the great majority of cases they are accompanied by fragments of lapilli and of pumice more or less altered. Vitreous volcanic matters belonging to the acid and basic series of rocks predominate in the regions where the red clay has its greatest development, and it will be seen presently that the most character-

istic decompositions which there take place are associated with pyroxenic lavas.

Associated with the red clay are almost always found concretions and microscopic particles of the oxides of iron and manganese, to which the deposit owes its colour. Again, in the typical examples of the deposit, zeolites in the form of crystals and crystalline spherules are present, along with metallic globules and silicates which are regarded as of cosmic origin. Calcareous organisms are so generally absent in the red clay that they cannot be regarded as characteristic; when present they are chiefly the shells of pelagic Foraminifera, and are usually met with in greater numbers in the surface layers of the deposit, to which they give a lighter colour. On the other hand, the remains of Diatoms, Radiolarians, and sponge spicules are generally present, and are sometimes very abundant. The ear-bones of various cetaceans, as well as the remnants of other cetacean bones, and the teeth of sharks, are, in some of the typical samples far removed from the continents, exceedingly abundant, and are often deeply impregnated with, or embedded in thick coatings of, oxides of iron and manganese. The remains of these vertebrates have seldom been dredged in the organic oozes, and still more rarely in the terrigenous deposits.

The *fine washings*, as examined with a power of 450 diameters, are composed of an amorphous matter, fragments of minerals, the remains of siliceous organisms, and colouring substances. What we call amorphous matter may be considered as properly the argillaceous matter, and presents characters essentially vague. It appears as a gelatinous substance, without definite contours, generally colourless, perfectly isotropic, and forms the base which agglutinates the other particles of the washings. As these physical properties are very indefinite, it is difficult to estimate even approximately the quantity present in a deposit. However, it augments in proportion as the deposit becomes more clayey, but we think that only a small quantity of this substance is necessary to give a clayey character to a deposit. Irregular fragments of minerals, small pieces of vitreous rocks, and remains of siliceous organisms predominate in this fundamental base. These particles probably make up about 50 per cent. of the whole mass of the *fine washings*, and this large percentage of foreign substances must necessarily

mask the character of the clayey matter in which they are embedded. The mineral particles are seldom larger than 0·01 mm. in diameter, but descend from this size to the merest points. It is impossible, on account of their minuteness, to say to what mineral species they belong, their optical reactions are insensible, their outlines too irregular, and all special coloration has disappeared. All that can be reasonably said is that these minute mineral particles probably belong to the same species as the larger particles in the same deposit, such as felspar, hornblende, magnetite, &c. In the case of pumice and siliceous organisms the fragments can, owing to their structure, be recognised when of a much less size than in the case of the above minerals.

It can be made out by means of the microscope that the colouring substances are hydrated oxides of iron and manganese. The former is scattered through the mass in a state of very fine division; in some points, however, it is more localised, the argillaceous matter here appearing with a browner tinge, but these spots are noticed gradually to disappear in the surrounding mass. The coloration given by the manganese is much more distinct; there are small rounded brownish spots with a diameter of less than 0·01 mm., which disappear under the action of hydrochloric acid with disengagement of chlorine. These small round concretions, which are probably a mixture of the oxides of iron and manganese, will be described with more detail in the "Challenger" Report.

The following table shows the nomenclature we have adopted:—

Terrigenous deposits.	Shore formations, Blue mud, Green mud and sand, Red mud,	Found in inland seas and along the shores of continents.
	Coral mud and sand, Coralline mud and sand, Volcanic mud and sand,	Found about oceanic islands and along the shores of continents.
Pelagic deposits.	Red clay, Globigerina ooze, Pteropod ooze, Diatom ooze, Radiolarian ooze,	Found in the abysmal regions of the ocean basins.

Geographical and Bathymetrical Distribution.—In the preceding pages we have confined our remarks essentially to the lithological nature of the deep-sea deposits, including in this term the dead shells and skeletons of organisms. From this point of view it has been possible to define the sediments and to give them distinctive names. We now proceed to consider their geographical and bathymetrical distribution, and the relations which exist between the mineralogical and organic composition, and the different areas of the ocean in which they are formed.

A cursory glance at the geographical distribution shows that the deposits which we have designated MUDS and SANDS are situated at various depths at no great distance from the land, while the ORGANIC OOZES and RED CLAYS occupy the abysmal regions of the ocean basins far from land. Leaving out of view the coral and volcanic muds and sands which are found principally around oceanic islands, we notice that our blue muds, green muds and sands, red muds, together with all the coast and shore formations, are situated along the margins of the continents and in enclosed and partially enclosed seas. The chief characteristic of these deposits is the presence in them of continental débris. The blue muds are found in all the deeper parts of the regions just indicated, and especially near the embouchures of rivers. Red muds do not differ much from blue muds except in colour, due to the presence of ferruginous matter in great abundance, and we find them under the same conditions as the blue muds. The green muds and sands occupy, as a rule, portions of the coast where detrital matter from rivers is not apparently accumulating at a rapid rate, viz., on such places as the Agulhas Bank, off the east coast of Australia, off the coast of Spain, and at various points along the coast of America.

Let us cast a glance at the region occupied by terrigenous deposits, in which we include all truly littoral formations. This region extends from high-water mark down, it may be, to a depth of over four miles, and in a horizontal direction from 60 to perhaps 300 miles seawards, and includes, in the view we take, all inland seas, such as the North Sea, Norwegian Sea, Mediterranean Sea, Red Sea, China Sea, Japan Sea, Carribean Sea, and many others. It is the region of change and of variety with respect to light, temperature, motion, and biological conditions. In the surface

waters the temperature ranges from 80° Fahr. in the tropics, to 28° Fahr. in the polar regions. Below the surface, down to the nearly ice-cold water found at the lower limits of the region in the deep sea, there is in the tropics an equally great range of temperature. Plants and animals are abundant near the shore, and animals extend in relatively great abundance down to the lower limits of this region which is now covered by these terrigenous deposits. The specific gravity of the water varies much, owing to mixture with river water or great local evaporation, and this variation in its turn affects the fauna and flora. In the terrigenous region tides and currents produce their maximum effect, and these influences can in some instances be traced to a depth of 300 fathoms, or nearly 2000 feet. The upper or continental margin of the region is clearly defined by the high-water mark of the coast-line, which is constantly changing through breaker action, elevation, and subsidence. The lower or abysmal margin is less clearly marked out. It passes in most cases insensibly into the abysmal region, but may be regarded as ending when the mineral particles from the neighbouring continents begin to disappear from the deposits, which then pass into an organic ooze or a red clay.

Contrast with these those conditions which prevail in the abysmal region in which occur the organic oozes and red clay, the distribution of which will presently be considered. This area comprises vast undulating plains from two to five miles beneath the surface of the sea, the average being about three miles, here and there interrupted by huge volcanic cones (the oceanic islands). No sunlight ever reaches these deep cold tracts. The range of temperature over them is not more than 7°, viz., from 31° to 38° Fahr., and is apparently constant throughout the whole year in each locality. Plant life is absent, and although animals belonging to all the great types are present, there is no great variety of form or abundance of individuals. Change of any kind is exceedingly slow.

What is the distribution of deposits in this abysmal region of the earth's surface? In the tropical and temperate zones of the great oceans, which occupy about 110° of latitude between the two polar zones, at depths where the action of the waves is not felt, and at points to which the terrigenous materials do not extend,

there are now forming vast accumulations of *Globigerina* and other pelagic Foraminifera, coccoliths, rhabdoliths, shells of pelagic Molluscs, and remains of other organisms. These deposits may perhaps be called the sediments of median depths and of warmer zones, because they diminish in great depths and tend to disappear towards the poles. This fact is evidently in relation with the surface temperature of the ocean, and shows that pelagic Foraminifera and Molluscs live in the superficial waters of the sea, whence their dead shells fall to the bottom. Globigerina ooze is not found in enclosed seas nor in polar latitudes. In the Southern Hemisphere it has not been met with beyond the 50th parallel. In the Atlantic it is deposited upon the bottom at a very high latitude below the warm waters of the Gulf Stream, and is not observed under the cold descending polar current which runs south in the same latitude. These facts are readily explained, if we admit that this ooze is formed chiefly by the shells of surface organisms, which require an elevated temperature and a wide expanse of sea. But as long as the conditions of the surface are the same we would expect the deposits at the bottom also to remain the same. In showing that such is not the case, we are led to take into account an agent which is in direct correlation with the depth. We may regard it as established that the majority of the calcareous organisms, which make up the Globigerina and Pteropod oozes, live in the surface waters, and we may also take for granted that there is always a specific identity between the calcareous organisms which live at the surface, and the shells of these pelagic creatures found at the bottom. This observation will permit us to place in relation the organic deposits and those which are directly or indirectly the result of the chemical activity of the ocean. Globigerina ooze is found in the tropical zone at depths which do not exceed 2400 fathoms, but when depths of 3000 fathoms are explored in this zone of the Atlantic and Pacific, there is found an argillaceous deposit without, in many instances, any trace of calcareous organisms. When we descend from the "submarine plateaux" to depths which exceed 2250 fathoms the Globigerina ooze gradually disappears, passing into a greyish marl, and finally is wholly replaced by an argillaceous material which covers the bottom at all depths greater than 2900 fathoms.

The transition between the calcareous formations and the argillaceous ones takes place by almost insensible degrees. The thinner and more delicate shells disappear first. The thicker and larger shells lose little by little the sharpness of their contour, and appear to undergo a profound alteration. They assume a brownish colour, and break up in proportion as the calcareous constituent disappears. The red clay predominates more and more as the calcareous element diminishes in the deposit.

If we now recollect that the most important elements of the organic deposits have descended from the superficial waters, and that the variations in contour of the bottom of the sea cannot of themselves prevent the débris of animals and plants from accumulating upon the bottom, their absence in the red clay areas can only be explained by a decomposition, under the action of a cause which we must seek to discover.

Pteropod ooze, it will be remembered, is a calcareous organic deposit, in which the remains of Pteropods and other pelagic Mollusca are present, though they do not always form a preponderating constituent, and it has been found that their presence is in correlation with the bathymetrical distribution.

In studying the nature of the calcareous elements which are deposited in the pelagic areas, it has been noticed that, like the shells of the Foraminifera, those of the Thecosomatous Pteropoda, which live everywhere in the superficial waters, especially in the tropics, become fewer in number as the depth from which the sediments are derived increases. We have just observed that the shells of Foraminifera disappear gradually as we descend along a series of soundings from a point where the Globigerina ooze has abundance of carbonate of lime, towards deeper regions; but we notice also that when the sounding-rod brings up a graduated series of sediments from a declivity descending into deep water, among the calcareous shells those of the Pteropods and Heteropods disappear first in proportion as the depth increases. At depths less than 1400 fathoms in the tropics a Pteropod ooze is found with abundant remains of Heteropods and Pteropods; deeper soundings then give a Globigerina ooze without these molluscan remains; and in still greater depths, as before mentioned, there is a red clay in which calcareous organisms are nearly, if not quite, absent.

In this manner, then, it is shown that the remains of calcareous organisms are completely eliminated in the greatest depths of the ocean. For if such be not the case, why do we find all these shells at the bottom in the shallower depths, and not at all in the greater depths, although they are equally abundant on the surface at both places? There is reason to think that this solution of calcareous shells is due to the presence of carbonic acid throughout all depths of ocean water. It is well known that this substance, dissolved in water, is an energetic solvent of calcareous matter. The investigations of Buchanan and Dittmar have shown that carbonic acid exists in a free state in sea water, and in the second place, Dittmar's analyses show that deep-sea water contains more lime than surface water. This is a confirmation of the theory which regards carbonic acid as the agent concerned in the total or partial solution of the surface shells before or immediately after they reach the bottom of the ocean, and is likewise in relation with the fact, that in high latitudes where fewer calcareous organisms are found at the surface, their remains are removed at lesser depths than where these organisms are in greater abundance. It is not improbable that sea water itself may have some effect in the solution of carbonate of lime, and further, that the immense pressure to which water is subjected in great depths, may have an influence on its chemical activity. We await the result of further researches on this point, which have been undertaken in connection with the "Challenger" Reports. We are aware that objections have been raised to the explanation here advanced, on account of the alkalinity of sea water, but we may remark that alkalinity presents no difficulty which need be here considered.*

This interpretation permits us to explain how the remains of Diatoms and Radiolarians (surface organisms like the Foraminifera) are found in greater abundance in the red clay than in a Globigerina ooze. The action which suffices to dissolve the calcareous matter has little or no effect upon the silica, and so the siliceous shells accumulate. Nor is this view of the case opposed to the distribution of the Pteropod ooze. At first we should expect that the Foraminifera shells, being smaller, would disappear from a deposit before the Pteropod shells; but if we remember that the latter are very thin

* Dittmar, *Phys. Chem. Chall. Exp.*, Part i., 1884.

and delicate, and, for the quantity of carbonate of lime present, offer a larger surface to the action of the solvent than the thicker, though smaller, Globigerina shells, we shall see the explanation of this apparent anomaly.

It remains now to point out the area occupied by the red clay. We have seen how it passes at its margins into organic calcareous oozes, found in the lesser depths of the abysmal regions, or into the siliceous organic oozes or terrigenous deposits. In its typical form the red clay occupies a larger area than any of the other true deep-sea deposits, covering the bottom in vast regions of the North and South Pacific, Atlantic, and Indian Oceans. As above remarked, this clay may be said to be universally distributed over the floor of the oceanic basins; but it only appears as a true deposit at points where the siliceous and calcareous organisms do not conceal its proper characters.

Having now indicated its distribution, we must consider the mode of its formation, and give, in addition, a concise description of the minerals and of the organic remains which are commonly associated with it. The origin of these vast deposits of clay is a problem of the highest interest. It was at first supposed that these sediments were composed of microscopic particles arising from the disintegration of the rocks by rivers and by the waves on the coasts. It was believed that the matters held in suspension were carried far and wide by currents, and gradually fell to the bottom of the sea. But the uniformity of composition presented by these deposits was a great objection to this view. It could be shown, as we have mentioned above, that mineral particles, even of the smallest dimensions, continually set adrift upon disturbed waters must, owing to a property of sea water, eventually be precipitated at no great distance from land. It has also been supposed that these argillaceous deposits owe their origin to the inorganic residue of the calcareous shells which are dissolved away in deep water, but this view has no foundation in fact. Everything seems to show that the formation of the clay is due to the decomposition of fragmentary volcanic products, whose presence can be detected over the whole floor of the ocean.

These volcanic materials are derived from floating pumice and volcanic ashes ejected to great distances by terrestrial volcanoes, and carried far by the winds. It is also known that beds of lava and of tufa

are laid down upon the bottom of the sea. This assemblage of pyrogenic rocks, rich in aluminous silicates, decomposes under the chemical action of the water, and gives rise, in the same way as do terrestrial volcanic rocks, to argillaceous matters, according to reactions, which we can always observe on the surface of the globe, and which are too well known to need special mention here.

The detailed microscopic examination of hundreds of soundings has shown that we can always demonstrate in the argillaceous matter the presence of pumice, of lapilli, of silicates, and other volcanic minerals in various stages of decomposition.

As we have shown in another paper,* the deposit most widely distributed over the bed of modern seas is due to the decomposition of the products of the internal activity of the globe, and the final result of the chemical action of sea water is seen in the formation of this argillaceous matter, which is found everywhere in deep-sea deposits, sometimes concealed by the abundance of siliceous or calcareous organisms, sometimes appearing with its own proper characteristics associated with mineral substances, some of which allow us to appreciate the extreme slowness of its formation, or whose presence corroborates the theory advanced to explain its origin.

In the places where this red clay attains its most typical development, we may follow, step by step, the transformation of the volcanic fragments into argillaceous matter. It may be said to be the direct product of the decomposition of the basic rocks, represented by volcanic glasses, such as hyalomelan and tachylite. This decomposition, in spite of the temperature approximating to zero (32° F.), gives rise, as an ultimate product, to clearly crystallised minerals, which may be considered the most remarkable products of the chemical action of the sea upon the volcanic matters undergoing decomposition. These microscopic crystals are zeolites lying free in the deposit, and are met with in greatest abundance in the typical red clay areas of the central Pacific. They are simple, twinned, or spheroidal groups which scarcely exceed half a millimetre in diameter. The crystallographic and chemical study of them shows that they must be referred to Christianite. It is known how easily the zeolites crystallise in the pores of eruptive rocks in process of decomposition; and the crystals of Christianite, which we

* "On Cosmic and Volcanic Dust," *Proc. Roy. Soc. Edin.*, 1883-84.

observe in considerable quantities in the clay of the centre of the Pacific, have been formed at the expense of the decomposing volcanic matters spread out upon the bed of that ocean.

In connection with this formation of zeolites, reference may be made to a chemical process whose principal seat is the red clay areas, and which gives rise to nodules of manganiferous iron. This substance is almost universally distributed in oceanic sediments, yet it is not so much of the areas of its abundance that we intend to speak as to the fact of its occurrence in the red clay, because this association tends to show a common relation of origin. It is exactly in those regions where there is an accumulation of pyroxenic lavas in decomposition, containing silicates with a base of manganese and iron, such for example as augite, hornblende, olivine, magnetite, and basic glasses, that manganese nodules occur in greatest numbers. In the regions where the sedimentary action, mechanical and organic, is, as it were, suspended, and where, as will appear in the sequel, everything shows an extreme slowness of deposition,—in these calm waters favourable to chemical reactions, ferro-manganiferous substances form concretions around organic and inorganic centres.

These concentrations of ferric and manganic oxides, mixed with argillaceous materials, whose form and dimensions are extremely variable, belong generally to the earthy variety or wad, but pass sometimes, though rarely, into varieties of hydrated oxide of manganese with distinct indications of radially fibrous crystallisation. The interpretation to which we are led, in order to explain this formation of manganese nodules, is the same as that which is admitted in explanation of the formation of coatings of this material on the surface of terrestrial rocks. These salts of manganese and iron, dissolved in water by carbonic acid, then precipitated in the form of carbonate of protoxide of iron and manganese, become oxidised, and give rise in the calm and deep oceanic regions to more or less pure ferro-manganiferous concretions. At the same time it must be admitted that rivers may bring to the ocean a contribution of these same substances.

Among the bodies which, in certain regions where red clay predominates, serve as centres for these manganiferous nodules, are the remains of vertebrates. These remains are the hardest parts of the skeleton—tympanic bones of whales, beaks of Ziphius, teeth of

sharks; and just as the calcareous shells are eliminated in the depths, so all the remains of the larger vertebrates are absent except the most resistant portions. These bones often serve as a centre for the manganese-iron concretions, being frequently surrounded by layers several centimetres in thickness. In the same dredgings on the red clay areas, some sharks' teeth and cetacean ear-bones, some of which belong to extinct species, are surrounded with thick layers of the manganese, and others with merely a slight coating. We will make use of these facts to establish the conclusions which terminate this paper.

In these red clays there occur, in addition, the greatest number of cosmic metallic spherules, or chondres, the nature and characters of which we have pointed out elsewhere.* We merely indicate their presence here, as we will support our conclusions by a reference to their distribution.

Reviewing, then, the distribution of oceanic deposits, we may summarise thus:—

(1) The terrigenous deposits, the blue muds, green muds and sands, red muds, volcanic muds and sands, coral muds and sands, are met with in those regions of the ocean nearest to land. With the exception of the volcanic muds and sands, and coral muds and sands, around oceanic islands, these deposits are found only along the borders of continents and continental islands, and in enclosed and partially enclosed seas.

(2) The organic oozes and red clay are confined to the abysmal regions of the ocean basins; a Pteropod ooze is met with in tropical and subtropical regions in depths less than 1500 fathoms, a Globigerina ooze in the same regions between the depths of 500 and 2800 fathoms, a Radiolarian ooze in the central portions of the Pacific at depths greater than 2500 fathoms, a Diatom ooze in the Southern Ocean south of the latitude of 45° South, a red clay anywhere within the latitudes of 45° north and south at depths greater than 2200 fathoms.

Conclusions.—All the facts and details enumerated in the foregoing pages point to certain conclusions which are of considerable geological interest, and which appear to be warranted by the present state of our investigations.

* "On Cosmic and Volcanic Dust," *Proc. Roy. Soc. Edin.*, 1883–4.

We have said that the débris carried away from the land accumulates at the bottom of the sea before reaching the abysmal regions of the ocean. It is only in exceptional cases that the finest terrigenous materials are transported several hundred miles from the shores. In place of layers formed of pebbles and clastic elements with grains of considerable dimensions, which play so large a part in the composition of emerged lands, the great areas of the ocean basins are covered by the microscopic remains of pelagic organisms, or by the deposits coming from the alteration of volcanic products. The distinctive elements that appear in the river and coast sediments are, properly speaking, wanting in the great depths far distant from the coasts. To such a degree is this the case that in a great number of soundings, from the centre of the Pacific for example, we have not been able to distinguish mineral particles on which the mechanical action of water had left its imprint, and quartz is so rare that it may be said to be absent. It is sufficient to indicate these facts in order to make apparent the profound differences which separate the deposits of the abysmal areas of the ocean basins from the series of rocks in the geological formations. As regards the vast deposits of red clay, with its manganese concretions, its zeolites, cosmic dust, and remains of vertebrates, and the organic oozes which are spread out over the bed of the central Pacific, Atlantic, and Indian oceans, have they their analogues in the geological series of rocks? If it be proved that in the sedimentary strata the pelagic sediments are not represented, it follows that deep and extended oceans like those of the present day cannot formerly have occupied the areas of the present continents, and as a corollary the great lines of the ocean basins and continents must have been marked out from the earliest geological ages. We thus get a new confirmation of the opinion of the permanence of the continental areas.

But without asserting in a positive manner that the terrestrial areas and the areas covered by the waters of the great ocean basins have had their main lines marked out since the commencement of geological history, it is, nevertheless, a fact, proved by the evidence derived from a study of the pelagic sediments, that these areas have a great antiquity. The accumulation of sharks' teeth, of the ear-bones of cetaceans, of manganese concretions, of zeolites,

of volcanic material in an advanced state of decomposition, and of cosmic dust, at points far removed from the continents, prove this. There is no reason for supposing that the parts of the ocean where these vertebrate remains are found are more frequented by sharks or cetaceans than other regions where they are never or only rarely dredged from the deposits at the bottom. When we remember also that these ear-bones, teeth of sharks, and volcanic fragments, are sometimes incrusted with two centimetres of manganese oxide, while others have a mere coating, and that some of the bones and teeth belong to extinct species, we may conclude with great certainty that the clays of these oceanic basins have accumulated with extreme slowness. It is indeed almost beyond question that the red clay regions of the central Pacific contain accumulations belonging to geological ages different from our own. The great antiquity of these formations is likewise confirmed in a striking manner by the presence of cosmic fragments, the nature of which we have described.* In order to account for the accumulation of all these substances in such relatively great abundance in the areas where they were dredged, it is necessary to suppose the oceanic basins to have remained the same for a vast period of time.

The sharks' teeth, ear-bones, manganese nodules, altered volcanic fragments, zeolites, and cosmic dust, are met with in greatest abundance in the red clays of the central Pacific, at that point on the earth's surface farthest removed from continental land. They are less abundant in the Radiolarian ooze, are rare in the Globigerina, Diatom, and Pteropod oozes, and they have been dredged only in a few instances in the terrigenous deposits close to the shore. These substances are present in all the deposits, but owing to the abundance of other matters in the more rapidly forming deposits their presence is masked, and the chance of dredging them is reduced. We may then regard the greater or less abundance of these materials, which are so characteristic of a true red clay, as being a measure of the relative rate of accumulation of the marine sediments in which they lie. The terrigenous deposits accumulate most rapidly, then follow in order Pteropod ooze, Globigerina ooze, Diatom ooze, Radiolarian ooze, and, slowest of all, red clay.

* "On Cosmic and Volcanic Dust," *Proc. Roy. Soc. Edin.*

From the data now advanced it appears possible to deduce other conclusions important from a geological point of view. In the deposits due essentially to the action of the ocean, we are at once struck by the great variety of sediments which may accumulate in regions where the external conditions are almost identical. Again marine faunas and floras, at least those of the surface, differ greatly, both with respect to species and to relative abundance of individuals, in different regions of the ocean; and as their remains determine the character of the deposit in many instances, it is legitimate to conclude that the occurrence of organisms of a different nature in several beds is not an argument against the synchronism of the layers which contain them.

The small extent occupied by littoral formations, especially those of an arenaceous nature, shown by our investigations, and the relatively slow rate at which such deposits are formed along a stable coast, are matters of importance.

In the present state of things there does not appear to be anything to account for the enormous thickness of the clastic sediments making up certain geological formations, unless we consider the exceptional cases of erosion which are brought into play when a coast is undergoing constant elevation or subsidence. Great movements of the land are doubtless necessary for the formation of thick beds of transported matter like sandstones and conglomerates.

In this connection may be noted the fact that in certain regions of the deep sea no appreciable formation is now taking place. Hence the absence, in the sedimentary series, of a layer representing a definite horizon must not always be interpreted as proof either of the emergence of the bottom of the sea during the corresponding period, or of an ulterior erosion. Arenaceous formations of great thickness require seas of no great extent and coasts subject to frequent oscillations, which permit the shores to advance and retire. Along these, through all periods of the earth's history, the great marine sedimentary phenomena have taken place.

The continental geological formations, when compared with marine deposits of modern seas and oceans, present no analogues to the red clays, Radiolarian, Globigerina, Pteropod, and Diatom oozes. On the other hand, the terrigenous deposits of our lakes, shallow seas, enclosed seas, and the shores of the continents, reveal the equivalents

of our chalks, greensands, sandstones, conglomerates, shales, marls, and other sedimentary formations. Such formations as certain tertiary deposits of Italy, Radiolarian earth from Barbadoes, and portions of the Chalk where pelagic conditions are indicated, must be regarded as having been laid down rather along the border of a continent than in a true oceanic area. On the other hand, the argillaceous and calcareous rocks, recently discovered by Dr Guppy, in the upraised coral islands in the Solomon group, are nearly identical with the volcanic muds, and probably also with the Pteropod and Globigerina oozes of the Pacific.

Regions situated similarly to enclosed and shallow seas and the borders of the present continents appear to have been, throughout all geological ages, the theatre of the greatest and most remarkable changes; in short, all, or nearly all, the sedimentary rocks of the continents would seem to have been built up in areas like those now occupied by the terrigenous deposits, which we may designate "*the transitional or critical area of the earth's surface.*" This area occupies, we estimate, about two-eighths of the earth's surface, while the continental and abysmal areas occupy each about three-eighths.

During each era of the earth's history, the borders of some lands have sunk beneath the sea and been covered by marine sediments; while in other parts the terrigenous deposits have been elevated into dry land, and have carried with them a record of the organisms which flourished in the sea of the time. In this transitional area there has been throughout a continuity of geological and biological phenomena.

From these considerations it will be evident that the character of a deposit is determined much more by distance from the shore of a continent than by actual depth; and the same would appear to be the case with respect to the fauna spread over the floor of the present oceans. Dredgings near the shores of continents, in depths of 1000, 2000, or 3000 fathoms, are more productive both in species and individuals than dredgings at similar depths several hundred miles seawards. Again, among the few species dredged in the abysmal areas furthest removed from land, the majority show archaic characters, or belong to groups which have a wide distribution *in time* as well as over the floor of the present oceans. Such are the

Hexactinellida, Brachiopoda, Stalked Crinoids and other Echinoderms, &c.

As already mentioned, the transitional area is that which now shows the greatest variety in respect to biological and physical conditions, and in past time it has been subject to the most frequent and the greatest amount of change. The animals now living in this area may be regarded as the greatly modified descendants of those which have lived in similar regions in past geological ages, and some of whose ancestors have been preserved in the sedimentary rocks as fossils. On the other hand, many of the animals dredged in the abysmal regions are most probably also the descendants of animals which lived in the shallower waters of former geological periods, but descended into deep water to escape the severe struggle for existence which must always have obtained in those depths affected by light, heat, motion, and other conditions. Having found existence possible in the less favourable and deeper water, they may be regarded as having slowly spread themselves over the floor of the ocean, but without undergoing great modifications, owing to the extreme uniformity of the conditions and the absence of competition. Or we may suppose that in the depressions which have taken place near coasts, some species have been gradually carried down to deep water, have accommodated themselves to the new conditions, and have gradually migrated to the regions far from land. A few species may thus have migrated to the deep sea during each geological period. In this way the origin and distribution of the deep-sea fauna in the present oceans may in some measure be explained. In like manner, the pelagic fauna and flora of the ocean is most probably derived originally from the shore and shallow water. During each period of the earth's history a few animals and plants have been carried to sea, and have ultimately adopted a pelagic mode of life.

Without insisting strongly on the correctness of some of these deductions and conclusions, we present them for the consideration of naturalists and geologists, as the result of a long, careful, but as yet incomplete, investigation.

4. Note on a large Crystal of Calc-spar, found in Lough Corrib by Professor Tait. By the Abbé Renard.

The crystal of calcite found by Professor Tait presents very large dimensions for a specimen, with very simple, and, at the same time, very definite forms. This crystal shows the faces of the primitive rhombohedron of 105°, and is twinned with parallel axes. The two individuals which compose the crystal show the form of the cleavage rhombohedron R $(10\bar{1}1)$; they are applied to each other with symmetrical development with reference to the base *o*R (0001), and present the appearance of a simple crystal, although formed of two distinct halves, of which the upper belongs to one crystal and the lower to the other, the two individuals being complementary to each other. Along the twinning plane may be noticed a series of very regular grooves, which indicate a repetition of the twinning following the base. It must be noticed that the six faces do not present the same physical characters—two of them, the primitive faces of the crystal, are smooth; the other four, although having the same crystallographic sign, are faces of cleavage more brilliant than the others. They appear to show that the crystal, although found isolated by Professor Tait, was formerly attached. This is further demonstrated by the presence of irregular faces, which are not amenable to any mathematical law. These false faces may be seen on the superior and inferior portions of the crystal; they are granular, and without lustre, and cannot be confounded either with the crystal faces or with those of cleavage. They have been produced by the pressure exerted upon the crystal by the neighbouring crystals, which were developing at the same time. This consideration explains the anomalies which they show, when regarded from a geometrical point of view.

PRIVATE BUSINESS.

Mr George M. Low, Dr Frederick Hungerford Bowman, the Rev. Dr J. Gordon Macpherson, M.A.; Mr Charles Scott Dickson, advocate; and Mr Robert Traill Omond, were balloted for, and declared duly elected Fellows of the Society.

Monday, 18*th February* 1884.

Sheriff FORBES IRVINE, Vice-President, in the Chair.

The following Communications were read:—

1. On Radiation. By Professor Tait.

(*Abstract.*)

The first part of this communication was devoted to a recapitulation of the advances in the *Theory of Exchanges* made by Stewart in 1858, and published in the *Transactions* of the Society for that year. Such a recapitulation it will be seen is *necessary;* as Stewart's papers seem either to have fallen into oblivion or to be deemed unworthy of notice. It was pointed out that Stewart showed in these papers that the radiation within an impervious enclosure containing no source of heat must ultimately become, like the pressure of a non-gravitating fluid at rest, the same at all points and in all directions; but that this sameness is not, like that of fluid pressure, one of mere total amount; it extends to the quantity and quality of every one of the infinite series of wave-lengths involved. For, as one or more of the bodies may be *black*, the radiation is simply that of a black body at the temperature of the enclosure. Any new body, at the proper temperature, may be inserted in the enclosure without altering this state of things; and must *therefore* emit precisely the amount and quality which it absorbs. This remark contains *all* that is yet known on the subject. For we have only to assume for the purpose of reasoning, the existence of a substance partially, or wholly, opaque to one definite wave-length, and perfectly transparent to all others; or with any other limited properties we choose; and suppose it to be put (at the proper temperature) into the enclosure. If we next assume that its temperature when put in differs from that of the enclosure, the experimental fact that, in time, equilibrium of temperature is arrived at, shows that the radiation of any particular wave-length by a body increases with rise of temperature. And so forth.

Yet in the latest authoritative work on the subject, *Lehrbuch der*

Spektralanalyse, von Dr H. Kayser (Berlin, 1883), though historical details are freely given, the name of Stewart does not occur even once! There are in the same work other instances of historical error nearly as grave. Thus the physical analogy, by which Stokes in 1852 first explained the basis of spectrum analysis, is given in Dr Kayser's work; but it is introduced by the very peculiar phrase " . . . . . wollen wir versuchen, eine *mechanische Erklärung* der Erscheinungen zu geben, welche auf unsere Anschauungen über das Leuchten begründet ist . . . . . ;" and the name of Stokes is not even mentioned in connection with it!

The second part of the paper deals with the question of the limits of accuracy of the reasoning which led Stewart, and those who have followed him, to results of such vast importance. Dr Kayser, indeed, announces his intention "in aller Strenge mathematisch zu beweisen" the equality of emissive and absorptive powers. But the mere fact that phosphorescent bodies, such as luminous paint, give out visible radiations while at ordinary temperatures, shows at once that there are grave exceptions even to the fundamental statement that the utmost radiation, both as to quantity and as to quality, at any one temperature, is that of a black body :—and very simple considerations show that all the reasoning which has been applied to the subject is ultimately based on the *Second Law* of Thermodynamics (or Carnot's principle), and is therefore true only in the sense in which that law is true, *i.e*, in the statistical sense. The assumed ultimate uniformity of temperature in an enclosure, which is practically the basis of every demonstration of the extended law of exchanges, is merely an expression for the average of irregularities which are in the majority of cases too regularly spread, and on a scale too minute, to be detected by our senses, even when these are aided by the most delicate instruments. The kinetic theory of gases here furnishes us with something much closer than a mere analogy. For the very essence of what appears to us uniform temperature in a gas is the regularity of distribution of the irregularities of speed of the various particles. And, just as in every mass of gas there are a few particles moving with speed far greater than that of mean square, so it is at least probable that a black body at ordinary temperatures emits (though, of course, excessively feebly) radiations of wave-lengths corresponding to those of visible

light. Effects apparently or at least conceivably due to this cause have been obtained by various experimenters.

If we could realise a dynamical system, analogous to that of a gas on the kinetic theory, but such that none of the particles could have any but one of a certain limited number of definite speeds, and if there were *still* a tendency to the nearest statistical average, we should have something capable of explaining phosphoresence at ordinary temperatures.

2. On the Need for Decimal Subdivisions in Astronomy and Navigation, and on Tables requisite therefor. By Edward Sang, LL.D.

The abstract question as to what number would have been most advantageously taken for the basis of an arithmetical system has been put aside by the universal preference shown for the number ten. All nations having any culture count in tens. In the English language, traces remain of the old numeration by dozens and scores; the French still prefer to say "quatre-vingt seize," rather than "nonante-six." These vestiges serve to show that there has been change. But from the old Eastern languages all traces of any but the denary counting have disappeared.

It is in vain to argue that the number twelve is divisible by three and by four, or that the perfect number six has the preference; for, however strong the arguments may be, there is no likelihood that they shall overturn the universally adopted mode. Nay, when, purely as arithmeticians, we come to look into the matter, and consider the needs and capabilities of mankind, we find arguments of no mean weight in favour of the denary mode.

But, whatever question there may be about the convenience of one or of another basis, there can be no question as to the principle of uniformity in the plan. To count our money in dozens and scores, our weights in sevens, and our distances in elevens, must necessarily entail trouble and confusion. Our unreasoning adherence to the medley of British monies, weights, and measures, is indeed a subject of wonder. If there be fourteen pounds to the stone, why not fourteen ounces to the pound? Five and a half yards go to a perch, why not five perches and a half to the furlong?

We make our pound of seven thousand troy grains, and come down again with sixteen ounces to the pound!

The introduction of the Indian numerals and notation has brought the inconvenience of these haphazard schemes into strong relief. The whole power of this algorithm comes from its uniformity. The old scheme of counting by help of letters had proceeded decimally, its great convenience having led to its use among the Arabs, from whom it passed into Greece. In this scheme the value of the letters depends on their place in the Hebrew Elif Be, which place is fixed in the Arab's memory by the rhythm "ebjed hevves hota kelmen," &c., while the Greeks had to supply two new characters to fit it to their alphabet. The first group of nine letters are taken to signify units, the second group tens, and the third group hundreds. But the marks, in the Indian method, rise in value ten times for each step on the scale, and thus ten characters serve, and much more than serve, for the former twenty-eight.

We, who have never had to use the older method, can hardly appreciate the magnitude of the improvement. Adopted at once by men of science, it led to the decimal division of the radius, and to the construction of the canon of sines in its modern form. Passing to commercial men, it greatly facilitated their computations. In every branch of business its influence is felt. Thus Fahrenheit, when arranging his thermometers, divided the capacity of the bottle decimally, and estimated temperature by the expansion of mercury in ten-thousandth parts of its bulk; while Celsius, proceeding in another direction, placed one hundred degrees between the temperatures of freezing and boiling water. The chemist makes his analyses in hundredths; the banker discounts per cent.; in every quarter the struggle is in favour of decimals. Gunter contrived his chain of one hundred links in order that there might be one hundred thousand square links in an acre; the engineer graduates his levelling staff not in feet, inches, and eighths, but in feet and hundredths.

There is no doing without decimals; when, in making a proportion, we have to compare two quantities of one kind, we, as the arithmeticians say, bring them both to one denomination: 2 cwt. 3 qrs. 17 lbs. $11\frac{1}{4}$ oz. must be brought to quarter ounces, of which there are 20 845 in this quantity. That is to say, having found our old system to be unworkable, we have recourse to counting in

tens; and, moreover, the trouble of converting our confused measures into decimals exceeds that of the real business in hand. Every such conversion is a protest in favour of uniformity.

Of all the affairs to which calculation is applied, trigonometry and astronomy have reaped most copiously the benefits of the Indian algorithm. We have only to compare the laborious process by which Archimedes determined the ratio of the circumference to the diameter of a circle, or the parallax and distance of the moon, to perceive how effectively the new numerals smoothed the rough road of alpha, beta; iota, kappa. Yet, great as these benefits were, they failed to satisfy the growing needs of science. Each step in exactitude added to the toil of the computer, till, discouraged by the swelling crowd of multiplications and divisions, of proportions among the sines and cosines, the mean distances, excentricities, anomalies, and periodic times, Kepler began to despair of the future of his science. Can we, then, afford to mar these benefits by a slavish adherence to a scheme of subdivision, beautiful in its uniformity, dignified by its age, but inept to the actual requirements?

The successive division by sixty, into parts of the first, second, and third degree of minuteness, dates back from before the reach of authentic history; it speaks of a great advance and subsequent decay of knowledge, for the ancient stadium and the Chinese li agree, within an inch or two, with the third subdivision of the earth's circumference in this progression. The convenience of its numerous divisions has, no doubt, helped to retain it in use. Sixty combines, in this respect, the advantages of ten and twelve, but is far too large for numeration in the ordinary affairs of life. Its retention in the measurement of time and angle is a great hindrance to our progress.

In the exceedingly simple applications of trigonometry to land-measuring, we have very little to do even with the addition and subtraction of angles, nothing whatever with their ratios; and thus the character of the subdivision has, comparatively, little importance for the surveyor. Yet even he would be much helped by the centesimal division of the quadrant. It is a long time since the division of the azimuth circle into four quadrants of ninety degrees each was discarded; the bearings were then read, so many degrees to the east or west of north, so many degrees east or

west of south, the same number of degrees indicating four different directions. The awkwardness of this is obvious to us; division into two parts of 180° each was substituted, and this again is now superseded by the graduation all round to 360°, so that a number applies to one direction only; this gives great clearness to the field operations. Having observed, from the station A, the bearings of various signals, among others that of the station B, and having carried the theodolite thither, we wish so to plant it as that it may again indicate the bearings of other signals. For this purpose we so place the azimuth circle as that, on looking back to A, the reading may be exactly the opposite of the previous reading from A to B. As the seamen phrase it, we must box the compass; we have to add or subtract 180° as the case may be.

In computing the co-ordinates of the stations, by help of the traverse table, or by the logarithmic process, we have to note the change from addition to subtraction at 90°, 180°, 270°, 360°, and have to pass from the top to the bottom of the page at 45°, 135°, 225°, and 315°; changing sine into cosine, difference of latitude into departure. Whereas, with the centesimal division of the quadrant, the changes are at the hundreds and fifties, while the opposite directions differ by 200°. The improvement both in comfort and in freedom from mistakes needs not to be insisted on.

In astronomical work, the awkwardness of having two numerical systems is conspicuous. We observe a planet's opposition to the sun, and again another opposition; the interval of time is noted in days, hours, minutes, seconds; the change of longitude in signs, degrees, minutes, seconds; and thence, roughly, to compute the periodic time we have to make a proportion. If we had been habituated to count in sixties, and if the number 24 had not occurred, the calculation in sexagesimals would have been the natural one; our logarithms would, according to Nepair's own opinion, have had 60 for their basis, just as now they have 10. As things are, no one can make the calculation. We must turn the times and the angles into decimals, taking the day or the second as the unit of time, the degree perhaps or the second as that of angle; without decimals we are unable to move a single step.

Now these divisions are made for the purposes of calculation; intrinsically it is of no moment which way we count, the planetary

phenomena are not thereby affected; the matter is one purely of arithmetical convenience. Had the subdivisions been according to the powers of ten, these conversions and their attendant labour would have been saved. But it is not now and then only that these irksome conversions occur; they pervade every calculation in geodesy, navigation, astronomy. The estimate is not too high, that they double the labour of computation.

In astronomical works there is abundant evidence of the need for a change. While the reckoning of longitude in signs, used sixty years ago, is discarded in favour of the counting in degrees all round, thirds are quite disused, the second is divided into tenths and hundredths. The arguments for the planetary disturbances are given, not in degrees, but in thousandth parts of the entire revolution.

There is no work having greater authority in these matters than that most admirable one, the *Nautical Almanac*, and every page thereof proclaims the need for decimals. The right ascensions, declinations, latitudes, and longitudes are given to decimals of the second. Now, if the division of the second into 100 parts be better than into 60, why should we not adopt, as John Newton did in the *Trigonometria Britannica*, the centesimal division of the degree? There is, and there can be, no argument in favour of division by 60 down to seconds, that will not hold as well for thirds and for fourths; and the same instinct for convenience which leads to the decimal division of the second would, if it had its own way, lead to that of the degree, of the quadrant, and of the day.

But ease of calculation is not the only consideration. The sun's daily right-ascensions, to hundredths of a second, are accompanied by a column of variations in one hour; this, which is really needed for the sake of the inept computer, saves the division by 24. But this column occupies the place of the actual differences, needed by the strict computer for taking into account the variation of the variations. With decimal graduation one column would suffice for all, and the compiler of the almanac would be spared the labour. The same may be said of the sun's declinations and of the moon's hourly places, which are accompanied by variations in 10 minutes. In the last-mentioned there is a remarkably strong instance of the awkwardness of sixties. Thus the variation in declination is to be

seen written $112''\cdot37$, rather than $1'\cdot\cdot52''\cdot37$; it would be difficult to cite a more forcible example.

That triumph of skill, patience, and exactitude, the table of Lunar Distances, is a protest even stronger; therein the moon's distances from a star are given at intervals of three hours. In order to compute the Greenwich time of his observation, the mariner compares his observed distance (corrected for refraction and parallax) with those found in the almanac; he has therefore to make a proportion in sexagesimals. Seamen are understood to be so wedded to the present system, that they of all others would dislike a change; yet such are the torments of sexagesimals that, for the shunning of them, a column of proportional logarithms is contrived, and a special logarithmic system is arranged. Instead of having to work out a simple proportion, the seaman is drilled to use the proportional logarithm, whose nature, in ninety-nine cases out of a hundred, he does not comprehend.

In the higher branches of astronomical calculations, and in the application of trigonometry to mechanical and physical problems, the arcs and their various functions have to be compared, the mode of comparison being suited to the particular cases. When the arcs are homologues of angles measured by help of graduated instruments, their natural unit is the entire circumference; but their sines and tangents, having reference to rectilineal measure, are most conveniently compared with the radius. Hence it is that, in ordinary trigonometry, two units are employed; and hence also the convenient though somewhat illogical expression, "the sine of an angle," instead of "the sine of the arc homologous to an angle." But in many cases, notably in analytical investigations, the radius of the circle is made the basis of comparison both for arcs and for sines. Also, in computing the anomalies of the planets, the areas passed over by the radius-vector have to be considered, and it is much preferable to measure the sines in parts of the circumference, the areas in parts of the surface of the circle.

Thus we have often to pass from one unit of measure to another; with no system of subdivision can the transitions be made more easily (if at all) than by that of uniform decimal subdivision.

From whichever point of view the matter may be studied, the desirability of the change is clear; but there are difficulties in the

way; there are the prejudices of habit, the discomforts of transition, the existing mass of preparatory work suited to the old plan, and, above all, the mass of preparations needed for the new scheme, Here, indeed, the great obstacle lies.

Aside from the proposal of a change of system, a new computation of fundamental tables looms in the near future. The precision of modern measurements render it necessary, in astronomical speculations, to reckon to hundredths of a second of time, to tenths of a second of arc. Now when we determine an arc by help of (say) the seven-place logarithm of its tangent true in the last figure, the uncertainty arising from the omitted parts may amount to the fortieth part of a second; so that, since the logarithm itself is subject to several similar uncertainties, we may, notwithstanding all care, err by the tenth part of a second. But it is a sound principle that the accuracy of the arithmetical work should be clearly beyond that of observation, in order that no perceptible new error may be introduced, and thus the time is not very far distant when eight-place tables may be indispensable. Hence, in designing the canons for the decimal system, we must also look forward to increased precision.

Since by far the greater number of computations are done by help of logarithms, our first business is to see to the logarithmic canon. Beginning independently of all previous work, the logarithms of all primes up to 10,000 have been computed to 28 places, that they may be true to 25, each prime being put in relation to, at least, three others. The greatest discrepancy found amounted to unit in the 27th place, so that this fundamental table may be regarded as altogether free from error. The volumes I., II., III., placed on the Society's table, contain all the articulate steps of the work, with indices to the primes and to the divisors used; so that, if in any subsequent computation one of these divisors should recur, we are spared the labour of a new division. Thus for the logarithm of 6563, the three equalities were used

$$\begin{aligned} 32\,130\,000\,001 &= 11 \cdot 599 \cdot 743 \cdot 6563 \\ 627\,600\,001 &= 7 \cdot 19 \cdot 719 \cdot 6563 \\ 36\,930\,001 &= 17 \cdot 331 \cdot 6563 \end{aligned}$$

and the agreement furnished presumptive evidence of the accuracy

of the previous computations (themselves similarly checked) for the above eight primes 11, 599, 742; 7, 19, 719; 7, 331, and also for the prime divisors of 3213, 6276, 3693, namely, 17, 523, 1231. In this way the whole work is bound together by an intimate interlacing of tests. The search for the appropriate formulæ was greatly facilitated by Burckhardt's admirable "Table des Diviseurs," but the recent extensions of that table by Dase and by Glaisher would have been most welcome.

By the combination of these primes and by interpolation to second differences, the logarithms, to 15 places, of all numbers from 100 000 to 370 000 have been computed. The actual calculations are contained in the twenty-seven volumes herewith presented, and the transfers in nine.

These logarithms are necessarily liable to residual errors, whose amount, however, cannot exceed three units in the fifteenth place. Among a large number of verifications, made for other purposes, no error exceeding two units has been found.

They are accompanied by the first and second differences—differences of the third order would only appear in the sixteenth place even at the beginning of the canon.

By help of these differences we can interpolate the logarithm of a number of more than six effective figures; the work consisting of three multiplications. For the converse operation, that of computing the number corresponding to a logarithm not found in the table, we need to resolve an equation of the second degree. Now the first differences have *ten*, the second difference have *five* effective figures, and therefore, when the utmost precision is required, either of these interpolations is necessarily laborious.

For the purposes of shortening the work, and of avoiding the solution of the quadratic equation, the expedient used by Nepair in the computation of his original *canon mirificus*, is had recourse in a form modified to suit the present circumstances.

To get the logarithm of a number not in the table, it is enough to discover that of the ratio which it bears to the tabulated number immediately below it. Now this ratio itself is easily found by division, and, in our present case, is expressed by unit followed at an interval of at least five blanks, by other figures; its greatest possible value is 1,00001. In the volume marked *Auxiliary table* the

logarithms of such ratios are given for each of the ten thousand numbers from 1 000 000 000 to 1 000 010 000. This list serves the purposes of both of Nepair's *Tabulæ prima et secunda*, and gives us, by help of this easy division, the fifteen-place logarithm of any number whatever. Not only so; it also enables us to solve the converse problem, by help of a multiplication as easy.

But we may approach to the required result, from the tabulated numbers immediately above. So, in order to supply the means of verification, the auxiliary table is carried, on the other side, to ten thousand numbers below the same 1 000 000 000.

This addition to the canon, besides greatly lessening the labour in interpolating, lends itself readily to systematic computation.

The fundamental canon for trigonometry is that of sines: these to 25 places for each two thousandth part of the quadrant, and to 15 places for each ten thousandth part, have been computed strictly by second differences, verified at short intervals. In the volumes placed before the Society the actual calculations are contained: they are recorded in such a form that each sine may be instantly examined. The manner of the calculation afforded a continuous and complete check, and the table is believed not to contain a single error. From these, the canon of logarithmic sines and the other usual trigonometrical tables may easily be compiled to an exactitude far beyond the requirements of practice.

In a paper entitled "Nouveau Calcul des Mouvements elliptiques," printed in the *Memoirs of the Turin Academy for* 1879, the mean anomaly of a planet is deduced from its position by taking the sum or the difference of two circular segments. In order to reap the advantage of this exceedingly simple solution of Kepler's problem, we need first to compute the sines, measured, not in parts of the radius, but in parts of the circumference. The volume marked "Sines measured in Degrees" contains the whole calculation of this canon for each centesimal minute, and to ten decimal places of the quadrant.

From this table, that of circular segments, measured in degrees of the surface of the circle, for each of the 40 000 minutes of the entire circumference, has been composed. This table, though designed expressly for astronomical purposes, has its uses in other branches of science.

When the position of a planet in its orbit is given, the mean anomaly is obtained directly and almost by inspection; but when the mean anomaly is proposed, the position has to be got by the inverse use of the tables, that is by approximation. When the first estimate is reasonably near, the work is scarcely more laborious than an ordinary interpolation; and when, as in preparing the *equations of the centre*, the computations are to be made at stated intervals, the labour is insignificant.

For the purpose of guiding the first estimate in sporadic cases, the mean anomalies corresponding to each degree of position, and in orbits of every degree of eccentricity, are given in the volume A, titled Mean Anomalies, the results being given to ten decimal places, and in volume B to eight places, with differences and variations.

In Kepler's time the details of only six elliptic orbits needed to be worked out; now we have forty times as many. The motions of the cloud of specks, so small as to be seen only by help of the telescope, afford an opportunity of verifying and correcting our estimates of the relative masses of the major planets, so much the more valuable that the disturbances exerted by these miniature worlds upon their giant neighbours escape our power of detection. This new mode of calculation vastly reduces the labour of comparing the purely elliptic with the observed motions.

For all analytical investigations the arc, as well as its sine, cosine, and tangent, is reckoned in parts of the radius—an arrangement also suited for several other applications of trigonometry. From this point of view, the sine and cosine take their place among functions with recurring derivatives; they are most easily and rapidly computed in this connection, without reference to the properties of the circle, being regarded as functions equal to their second derivatives with the signs changed. The volume titled "Recurring Functions" contains their values to twelve decimal places, for each thousandth part of the radius, up to two radii.

For facilitating the change from the one unit to the other in the measurement of arcs, a table is here presented of the "Lengths of Circular Arcs" both for the ancient and for the modern graduation. The contrast in the arrangement of the two parts of this table affords an excellent example of the power and conciseness of the decimal system.

The lengths are given for each second of the ancient division up to one degree, in all 3600 values; thereafter for each degree up to 1800°, or five complete revolutions; the values for fractions of a second being got by the transposition of the numbers at the beginning of the table, this facility being due to the adoption of the decimal division for seconds.

For the modern division 1000 terms suffice, because by mere transposition the table may be extended indefinitely both ways.

In order to pass from the one system of subdivision of the quadrant to the other, a table of equivalent modern and ancient degrees is given, first from 10^c to 10^c or 9° to 9°; then for centesimal minutes up to 10° (computed for the sake of verification); next for each tenth decimal second up to the same limit; and, lastly, for each hundredth part of a second up to ten seconds. By this table the conversion of ancient into modern or of modern into ancient degrees is easily effected.

Similar tables for the conversion of ancient and decimal time are exhibited.

In the reduction of astronomical observations we have very often to exchange solar and sidereal time. In 1868 the writer published Time Conversion Tables for each tenth second of the whole day. The counterpart to these is herewith presented; it is continued from day to day up to 1000 days; and this suffices for minutes, seconds, and fractions by simple transposition.

Lastly, there is appended a Traverse Table, for plain and mean latitude sailing, for each of the 400 degrees of azimuth and for distances up to 100.

These form at least a beginning in the collection of requisite decimal tables. That which is first wanted beyond them is the canon of logarithmic sines. The preparation of this canon would be greatly facilitated by the extension of the fifteen-place logarithms up to the whole million—that is, for all six-figure numbers. Those of them already prepared need the aid of the auxiliary multipliers 2 and 3; had they been carried to the half million, the auxiliary 2 would have sufficed.

In conclusion, it may be remarked that five and seven place tables are exact enough for almost all business purposes; but that, in order to have these true to the last figure, the original calculations

must be carried several steps beyond; also, that while it is easy to abridge the lengthy results, it is impossible to extend those which have proved too short; then the work must be re-done from the beginning. Hence the great advantage already experienced in this: that Brigg's computations to fourteen places served for the preparation of Vlacq's ten-place table, and that again for those in common use, of seven and of five places.

An Electro-Magnetic Declinometer. By A. Tanakadaté, Assistant to the Professor of Physics in the University of Tokio, Japan. Communicated by Prof. J. A. Ewing, University College, Dundee.

The terrestrial magnetic field will in general be disturbed in the neighbourhood of an electric circuit; but if the circuit be a plane set at right angles to the terrestrial lines of force, the direction of the field will remain unchanged at all points in the plane of the circuit. To determine the magnetic meridian, we have only to place a plane circuit in such a direction that, when a current in the circuit is started and stopped, no change takes place in the position of a small magnet hung at a point in the plane of the circuit, and free to turn in azimuth. The plane of the circuit will then lie magnetically east and west.

The following method of laying down the magnetic meridian on, say, a laboratory table, will be found very convenient and accurate in practice:—

A light rectangular wooden frame is made, about 1 meter long, 15 cm. high, and 3 cm. wide, and its outer surface is recessed slightly, except at the edges, to receive 200 turns of fine insulated wire, which are wound regularly round the frame. Both ends of the coil are led off from the same point, and close together, in order to limit the electro-magnetic influence of the circuit to the portion wound on the frame. The circuit is completed at a considerable distance from the frame through a battery, reversing key, and box of resistance coils.

A small magnetometer, consisting of the mirror (with attached magnets) of a Thomson's dead-beat galvanometer, hung in a wood and glass case by a silk fibre 5 cm. long, is placed in the centre of this frame, resting upon a little shelf which projects into the middle

of the frame from an outside stand, so that the frame can be moved round or taken out of its place without disturbing the magnetometer. The displacement of the mirror is observed, as usual, by the motion of the reflected image of an illuminated slit or wire. The whole is shown in fig. 1.

To determine the magnetic meridian—

1. Place the frame in a vertical plane, with the magnetometer at its centre, and its length approximately at right angles to the magnetic meridian.

2. Observe the position of the reflected image on the magnetometer scale before closing the circuit.

3. Make the circuit so that the field due to it has the same sign as the terrestrial field. The image will in general be displaced, and its movements will be quickened on account of the increase of directive force. Turn the frame until the image comes back to its original position.

4. Reverse the current; unless the adjustment in operation 3 has been correct, the image will again be displaced. The current is to be regulated (by the resistance coil) to prevent the equilibrium from being unstable or too nearly neutral. Turn the frame, if need be, until the image comes to its original position. Now draw a line on the table, using one edge of the frame as a straight-edge, or in some other way note its position.

5. Break the current; remove the frame and replace it inverted, and with its former east end now pointing west. Repeat operations 1 to 4 in this position, and take for the magnetic E–W the mean of the two directions so determined.

If the edges of the frame are not strictly at right angles to the lines of force at its centre, but are inclined at an angle of $\frac{\pi}{2}+\alpha$ to them, the two determinations will differ by 2α, and their mean will be independent of α, provided the edges of the frame are strictly parallel, and the magnetic declination is constant during the operation.

Experiments with the above apparatus have shown that the error due to any small excentricity on the part of the magnetometer is inappreciable. The magnetometer was purposely placed 2 mm. away from the centre towards different quarters, but no sensible

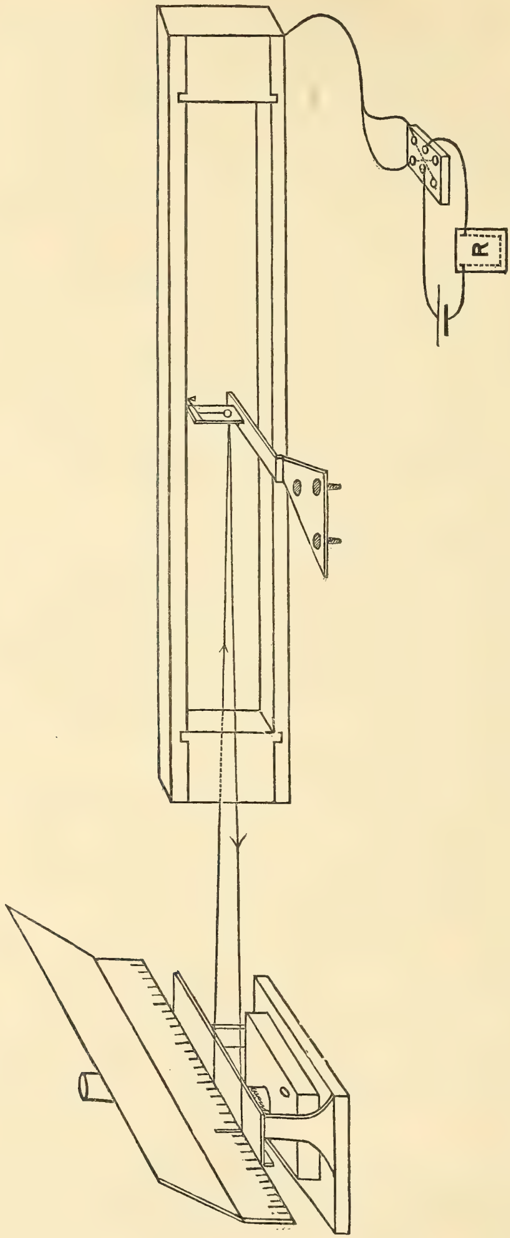


Fig. 1.

difference in the determined directions of the meridian was observed.

A much more elaborate instrument, based on the same principle, has been constructed for the accurate measurement of magnetic declination. In it the coil is wound in two parts on a bronze frame (the form of which will be described below), of much smaller size than in the simple laboratory apparatus already described. The frame has hollow pivots, and is mounted on the Y's of an altazimuth instrument. Fig. 2 is taken from a photograph of the instrument. The pivots are made as nearly as possible of the same size as those of the telescope which belongs to the instrument, and the total weight of the frame nearly equals that of the telescope.

A light mirror magnetometer stands between the two parts of the coil in the centre of the instrument, and is supported by an independent tripod, as in fig. 2, or by a central pillar fixed to the base. At the middle of two sides of the frame narrow slits, *a a*, are provided, through which the edge of the magnetometer mirror is to be sighted to bring it to a central position. It is centred with respect to the other horizontal and the vertical direction by sighting the face of the mirror through one of the hollow pivots, and making the clearance equal all round.

The magnetometer is shown separately in fig. 3. The mirror with attached magnets is suspended by a single silk-fibre 40 cm. long. The upper end of the fibre is tied round the middle of a small rod of horn, whose weight is nearly equal to that of the mirror and magnets. This rod rests on two small V hooks projecting down from the top of the magnetometer case. The hooks are united at the top, and can be turned or lowered by loosening a jam-nut. At the lower part of the magnetometer case a thin lens is fixed in front of the mirror. A little way above the mirror, a catch, consisting of a pair of inverted hooks, is fixed in the case, so that when the magnetometer is turned upside down, the mirror will be held by the catch, and the horn rod will hang free. This rod is then allowed to turn under the torsion of the fibre until that is completely removed. The V hooks are turned into the same azimuth as the hanging rod, and the magnetometer is then inverted, that is to say, restored to its normal position. It now hangs free, and without sensible initial torsion. It is next

to be placed in the centre of the coil (the coil being roughly in the magnetic E–W plane), and its position adjusted.

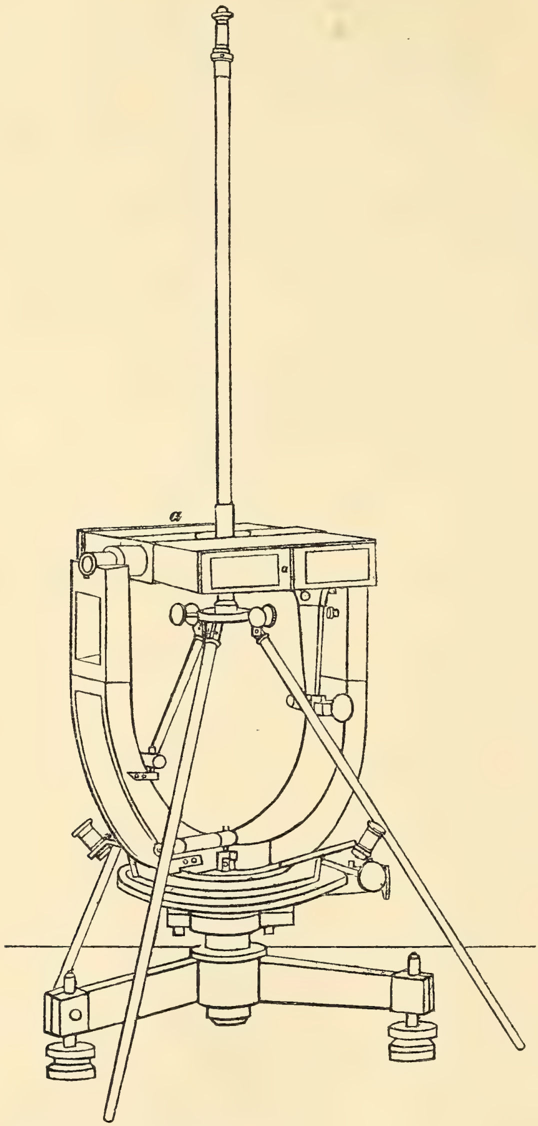


Fig. 2.

The method of observation is the same as in the previous case.

In inverting the coil, it is lifted from the Y's and raised vertically, care being taken not to touch the magnetometer case.

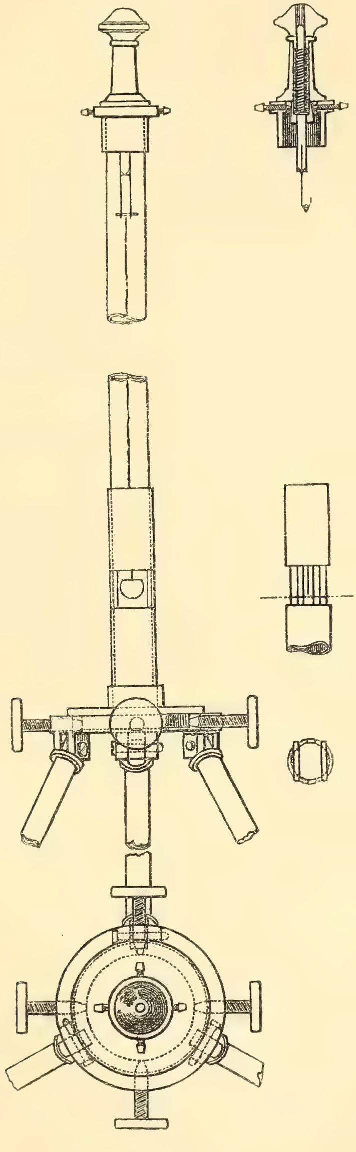


Fig. 3.

The two determined positions of the axis of the Y's, corresponding

to the original and inverted positions of the coil, are to be read on the azimuth circle.

To determine the astronomical meridian, the coil and the magnetometer are to be removed without displacing the base, and the telescope mounted. Any of the usual methods of observation can then be applied.

An alternative construction is to attach directly to the telescope a frame for the coil. This requires that the tube of the telescope be perforated in its middle to let in the magnetometer. The instrument becomes somewhat clumsy, but it has the advantage of allowing the same pivots to be used in both the magnetic and astronomical observations.

The sensibility of the apparatus (in either its simple or more elaborate form) may be investigated as follows:—

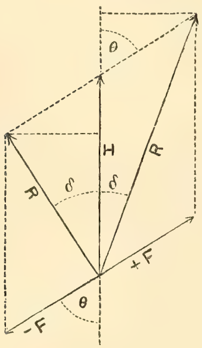


Fig. 4.

Let H be the horizontal component of the terrestrial field.

Let F be the field due to the coil alone.

Let θ be the angle between F and H.

Let δ be the angle between H and R, the resultant of H and F. This will be the angle through which the magnetometer is deflected when the current is made, and

$$\tan\delta = \frac{\pm F\sin\theta}{\pm F\cos\theta + H},$$

F having a + or − sign, according as its direction is the same or opposite to that of H.

Since δ and θ are small,

$$\delta = \frac{\pm F\theta}{\pm F + H} = \frac{\theta}{1 \pm \frac{H}{F}},$$

from which we see that δ, the deflection of the mirror due to any assigned error in the position of the coil, can be greatly magnified by making F a little less than and of opposite sign to H.

This magnification can be roughly measured by turning the frame through a known angle from its determined position, and observing

the displacement of the image when the current is made. There is no difficulty in detecting an error of 1″ in the position of the coil by the motion of the reflected image. Evidently this magnification must not be carried so far as to make the initial torsion of the fibre seriously comparable with the magnetic couple. The plan described above of depriving the fibre of initial torsion was introduced for this reason.

If the displacement of the mirror be observed with a sufficient degree of optical magnification, the process of giving sensibility by reversing F may be dispensed with. When $F = H$, δ becomes $\frac{1}{2}\theta$, and the angular displacement of the reflected ray is equal to the error in position of the fame.

The form of frame (with two parallel coils) shown in fig. 2 has been chosen in order to minimise the error produced by excentricity on the part of the magnetometer. The proportions of the frame have been calculated as follows :—

Let $a = \frac{1}{2}$ length of the frame.
„ $b = \frac{1}{2}$ height „
„ c_1 = distance of the nearer face of each coil from the centre.
„ c_2 = distance of the further face of each coil from the centre.

Suppose the coil be set with the plane of ab perpendicular to the magnetic meridian. Take the centre of the frame as origin of co-ordinates.

As we are only concerned with the direction in azimuth, we shall consider excentricity in the horizontal plane only. From the symmetry of figure there will be no error, so far as direction is concerned, when the centre of the magnet is on either axis NS or EW (see next figure).

Let the centre of the magnet be at a point $(\delta a, \delta c)$ from the origin. The angle which the lines of force at $(\delta a, \delta c)$ make with the axis of NS will be the error due to excentricity. Call this angle ϵ, then,

$$\tan \epsilon = \frac{\text{force in direction WE}}{\text{force in direction NS}},$$

$$= \frac{F_a}{F_c} \text{ say}.$$

When ϵ is small,

$$\epsilon = \frac{F_a}{F_c}.$$

To find F_a, which is the deviating force on the magnetometer—

Let ABCDA′B′C′D′ be a horizontal projection of the frame; and let the centre of the magnetometer be excentrically placed at the point (δa, δc).

By supposing the frame to be divided into two parts by a vertical plane, $dcd'c'$ (where $Ad = 2\delta a = A'd'$), and imagining pairs of equal and opposite currents to flow in this plane up and down, we may resolve the circuit into two pairs of coils, dcCD, $d'c'$C′D′, and ABcd, A′B′$c'd'$.

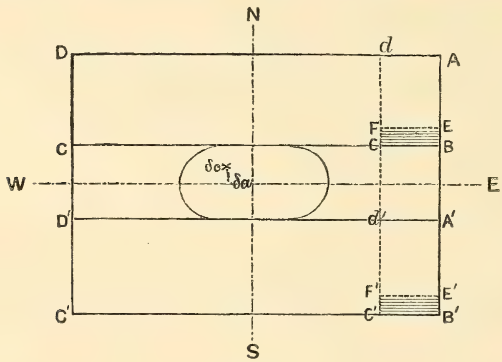


Fig. 5.

The former pair, being symmetrically placed with respect to the assumed position of the magnetometer, will give no deviating force; and in finding F_a we have only to consider the remaining pair, namely, ABcd, A′B′$c'd'$. Again, suppose two vertical planes, EF and E′F′, to be drawn parallel to the planes of the coils, making EB $= \delta c$* $=$ E′B′. In this way the remaining pair is again divided into two pairs, AEFd, A′E′F′d', and EBcF, E′B′c'F′; of these the former, being placed symmetrically with regard to the magnetometer, will give no deviating force.

We are thus left with a pair of narrow magnetic shells EBcF and E′B′c'F′, the breadth of each shell being $2\delta a$, height $2b$, and thickness

* [Evidently this should be $2\delta c$, not δc. The mistake, which I have noticed only in reading the proof, does not affect the accuracy of Mr Tanakadaté's conclusions as to the proper proportions of the coils; and the equations which follow, as well as the numerical values given in fig. 8, need not be altered, if we assume the excentricity of the magnetometer in the direction NS to be $\frac{1}{2}\delta c$ instead of δc as in the text.—J. A. E.]

δc.* Since $2\delta a$ and δc* are supposed to be small compared with the height $2b$, these shells may be treated as electromagnetic *strips.*

The two strips we are considering, being on opposite sides of the origin, will produce deviating forces with opposite signs. Hence if the numerical magnitudes of the forces they cause are equal, they will produce no deviating effect on the magnetometer.

Now it is evident, if such a magnetic strip be placed due east or

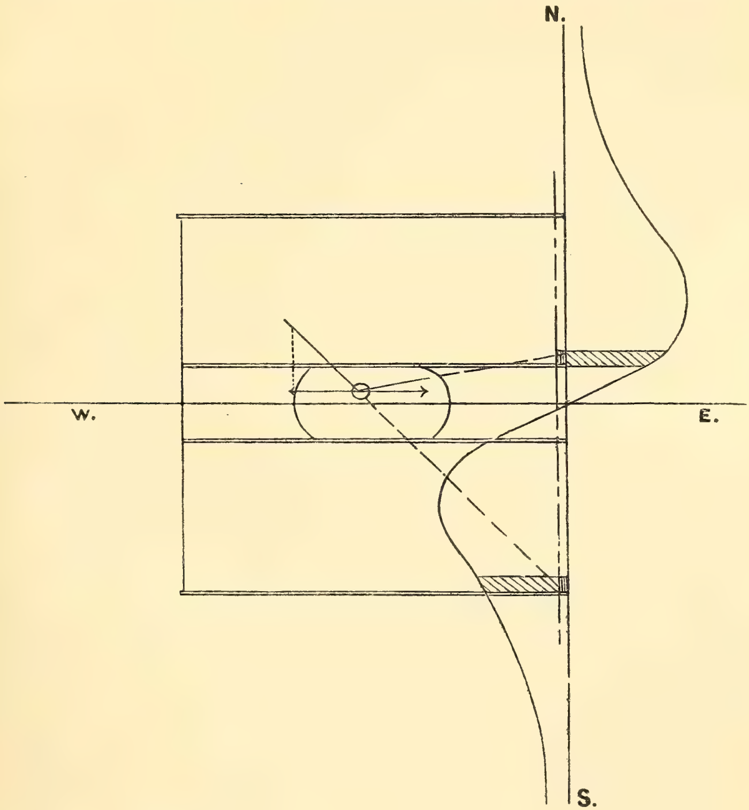


Fig. 6.

due west of the magnetometer with its plane at right angles to the magnetic meridian, the deviating force due to it will be zero. But if its position be changed along the magnetic meridian, without any rotation, the deviating force will increase, pass a maximum, and again become insensible when the strip is carried to a very great

* See note, p. 552.

distance. If the strip be moved in the opposite direction, the same thing will happen with the opposite sign. Hence if we make the frame on which the coils are wound such that the values of the deviating forces due to the two strips EBcF and E$'$B$'c'$F$'$ are numerically equal, the former being on the nearer side of the positive maximum and the latter on the further side of the negative maximum, the deviating force on the magnetometer will be insensible. This is illustrated by fig. 6, where the curve shows the deviating force caused by a strip in various positions along the line NS.

To find the action of each magnetic strip—

Let NS in the annexed figure represent the magnetic meridian. Let the centre of the magnetic strip be on the line ns, parallel to N S, and let the magnetometer be placed at m. From the preceding figure it will be evident that the breadth of the strip is $2\delta a$, its thickness δc, its length $2b$, and the distance of its centre from N S is a. Further, let c be the distance of its centre from WE, and r the distance from m.

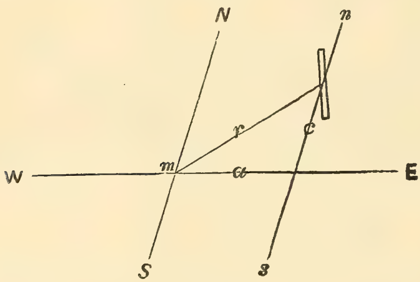


Fig. 7.

To find the force in the direction of a, which is the deviating force, we have to find the solid angle ω subtended by the area of the strip at the point m; differentiate it with respect to a; multiply the result by $in\delta c$, where i is the strength of the current, and n the number of turns of wire per unit of length.

Since the strip is supposed to be very narrow, we can, without sensible error, project the area perpendicular to the direction of r, and take ω subtended by this projected area in finding the potential at the point m due to the strip. To do this we have only to find the solid angle subtended by a rectangle whose height is $2b$ and breadth $2\delta a\frac{c}{r}$, namely,

$$\omega = 4\cos^{-1}\frac{\left(\delta a\frac{c}{r}\right)b}{\sqrt{(b^2+r^2)\left(\overline{\delta a\frac{c}{r}}\Big|^2+r^2\right)}} - 2\pi.$$

Hence, neglecting terms involving $(\delta a)^2$, the potential

$$V = in\delta c\left\{4\cos^{-1}\frac{\delta acb}{r^2\sqrt{b^2+r^2}} - 2\pi\right\}.$$

$$F_a = \frac{dV}{da} = \frac{dV}{dr}\,\frac{dr}{da}$$

$$= 4in\delta c\frac{\delta a\, abc(3r^2+2b^2)}{r^4(b^2+r^2)^{\frac{3}{2}}},$$

or

$$F_a = \frac{4abc(3a^2+2b^2+3c^2)}{(a^2+c^2)^2(a^2+b^2+c^2)^{\frac{3}{2}}}in\delta a\delta c.$$

This result can also be arrived at by finding the solid angle subtended by the whole rectangle $2a$, $2b$ at the point m. Multiplying this by $in\delta c$ we have the potential due to the whole shell $2a$, $2b$, δc, and differentiating with respect to a we obtain the force at m in the direction of a: this will evidently be zero. But differentiating this again with respect to a, and multiplying the result by δa, we obtain for the action of the magnetic strip a value which agrees with the above result.

Differentiating the coefficient $\dfrac{4abc(3a^2+2b^2+3c^2)}{(a^2+c^2)^2(a^2+b^2+c^2)^{\frac{3}{2}}}$ with respect to c to find the maximum value of the deviating force, we obtain an equation which is cubic with respect to c^2, from which it can be proved that the maximum value of the coefficient lies between $c=\dfrac{a}{2}$ and $c=\dfrac{a}{\sqrt{3}}$ for all real values of b.

In fig. 8, the values of the above coefficient for various values of c are represented in curves, the length being expressed in centimeters.

Curve I gives the values of the coefficient when $a=10$ and $b=\delta b$ (that is when the strip is indefinitely short). In this case,

$$F_a = \frac{12ac}{(a^2+c^2)^{\frac{5}{2}}}in\delta a\delta b\delta c.$$

The curve may be interpreted as a diagram representing the deviating force exerted by a magnetic particle, whose moment is 4 (in C. G. S. units) upon a unit magnetic pole at m.

Curve II is for the case $a=10$ $b=2$;
Curve III ,, ,, $a=10$ $b=\frac{10}{3}$;
Curve IV ,, ,, $a=10$ $b=\infty$.

This last may be interpreted as a diagram representing the deviating force due to an indefinitely long wire hung vertically and magnet-

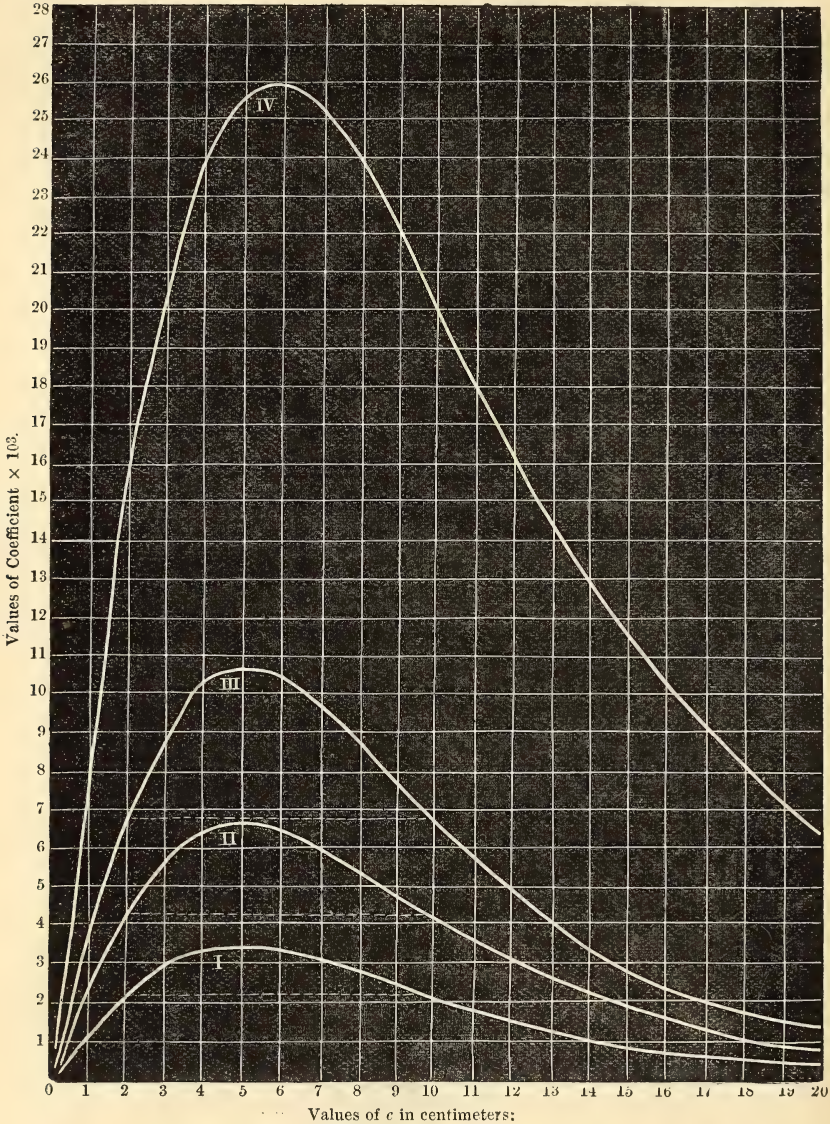


Fig 8

ised uniformly in a transverse direction parallel to c, its magnetic moment per unit length being 2 in C. G. S. units. In this case

$$F_a = \frac{8ac}{(a^2+c^2)^2} in\delta a\delta c.$$

From the curves it is to be observed that the ordinates have

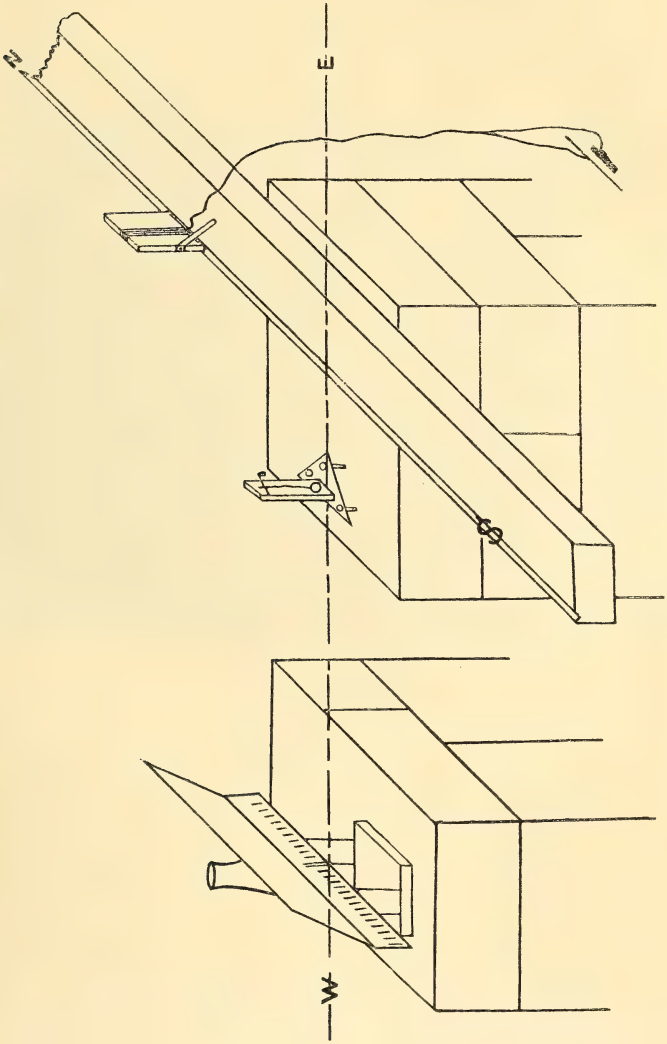


Fig. 9.

nearly equal values at $c=10$ and $c=2$ for curves I, II, and III.

Hence we find that the effect of any small excentricity will be a minimum with practically any value of b between 0 and 3, provided the coils are wound so that the ratio of $a : c_1 : c_2$ is $10 : 2 : 10$. The frame actually used has the following dimensions:—$a = 9$ cm., $b = 1.8$ cm., $c_1 = 1.8$ cm., $c_2 = 9$ cm.

[Independently of the above calculation, the deviating effect of a magnetic strip was determined experimentally. Upon a rectangular plate of wood a coil of wire was wound so as practically to represent an electromagnetic strip, with the following dimensions :—

Internal width of the strip	=	0·37	cm.
Internal height " "	=	9·1	"
External width " "	=	0·7	"
External height " "	=	10·1	"
Thickness " "	=	0·34	"
Number of turns of wire	=	49	

A strong uniform current was supplied by four large gravity cells. The strip stood upright on two round legs in a V groove which was placed along the magnetic meridian, and 30 cm. east of the magnetometer, which hung in a horizontal plane through the bottom of the strip. To increase the sensibility, the directive field was considerably weakened without change of direction by using a permanent magnet. The apparatus is shown in fig. 9.

Calling θ the deflection of the magnetometer,

$$\tan\theta = \frac{i\dfrac{d\omega}{dx}}{H + i\dfrac{d\omega}{dy}},$$

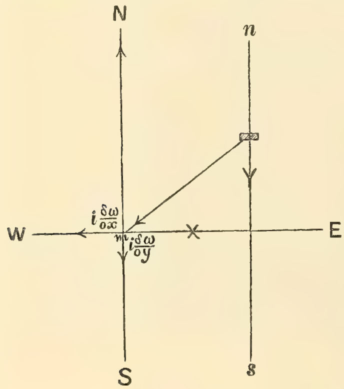


Fig. 10.

with the usual notation. But since $i\dfrac{d\omega}{dy}$ is small compared with H, we may take the deviating force as nearly proportional to tan θ. Fig. 11 gives the curve plotted from this experiment. It will be seen that the fall after passing the maximum is rather rapid compared with that in curve III in fig. 8, which, allowing for change of scale,

represents the same conditions as those of the experiment, probably because of the neglected effect of $\left.i\frac{d\omega}{dy}\right]$.

With a frame constructed as described, the error due to any small excentric position of the magnetometer is insensible. Practically, however, there will be some difference of thickness in the front and rear coils due to imperfect workmanship. We shall make a liberal allowance by supposing that one coil is broader than the other by

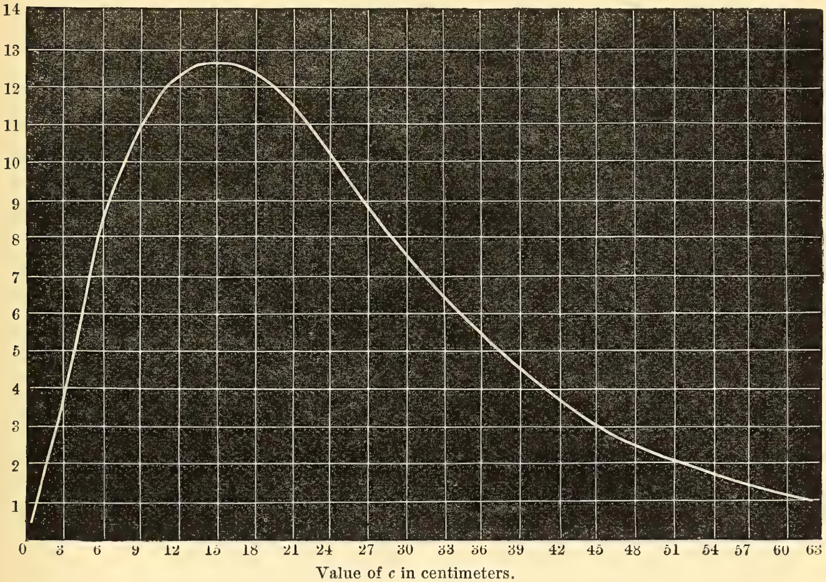


Fig. 11.

1 mm. Also let the magnetometer be placed 1 mm. east or west of the centre of the frame. The value of the deviating force will then be the value of the ordinate at $c = 10$ in curve II., fig. 8, multiplied by $in \times 0.1 \times 0.1$, which is $0.0042 \times 0.01 \times in = 0.000042\ in$. This, divided by F_c, the force along the axis NS, will give the angle ϵ (page 551).

To find F_c in the assumed conditions of excentricity :—

Let ω be the solid angle subtended at m by a thin shell whose thickness is δc, and $n =$ the number of turns per unit length. Then, using the same notation as before,

$$dF_c = in\delta c\frac{d\omega}{dc} = ind\omega\,.$$

$$F = \int_{c_1}^{c_2} dF_c = in \int_{c=c_1}^{c=c_2} d\omega$$

$$= in[\omega_1 - \omega_2] \text{ say.}$$

If we take both the front and rear coils this must be doubled, thus—

$$F_c = 2in[\omega_1 - \omega_2]$$

$$= 8in\left[\cos^{-1}\frac{ab}{\sqrt{(c_1^2 + a^2)(c_1^2 + b^2)}} - \cos^{-1}\frac{ab}{\sqrt{(c_2^2 + a^2)(c_2^2 + b^2)}}\right]$$

$$= 8in(\phi_1 - \phi_2) \text{ say.}$$

When $a = 10$; $b = 2$; $c_1 = 2$; $c_2 = 10$,

$$\phi_1 - \phi_2 = 35°56' \text{ or } 0.627 \text{ radians.}$$

Thus $$F_c = 8in \times 0.627 = 5.02in.$$

Hence $$\epsilon = \frac{F_a}{F_c} = \frac{0.000042in}{5.02in}$$

$$= 0.0000084 \text{ radians}$$

$$= 1''.7 .$$

In practice there should be no difficulty in keeping δa and δc within $\frac{1}{2}$ mm., in which case the error will be limited to one quarter of the above.

The paper has been kindly revised by Professor J. A. Ewing, for whose instructions my obligations are manifold.

[*Note added August* 1884.—In a letter of dated April 27, Mr Tanakadaté describes how, by the use of spider-thread instead of silk-fibre for the suspension of the magnetometer mirror and magnet, he has succeeded in reducing the error due to initial torsion to an altogether insignificant amount. He also suggests a method of optically magnifying the displacement of the mirror by hanging it in a chamber containing a liquid with a high index of refraction μ. The front of the chamber is of glass, and the mirror hangs parallel to it. If ψ be the angle of incidence, on the outside of the face of the chamber, of the entering ray, then for any small angular displacement of the mirror the reflected ray, on leaving the chamber, will be turned through an angle which is $2\sqrt{(\mu^2 - 1)\sec^2\psi + 1}$ times the angle turned through by the mirror. The reflected image will of course form a spectrum, but this is of no consequence when, as here, the method of observation is a *nul* method.—J. A. E.].

4. On an Equation in Quaternion Differences. By Professor Tait.

(*Abstract.*)

When the sides of a closed polygon are bisected, and the points of bisection joined in order, a new polygon is formed. It has the same number of sides, and the same *mean point* of its corners, as the original polygon. In what cases is it similar to the original polygon? In what cases will two, three, or more successive operations of this kind produce (for the first time) a polygon similar to the original one?

Take the mean point as origin, and let $q_1\alpha$, $q_2\alpha$, . . . $q_n\alpha$, be the n corners. Here α is any vector, which, if the polygon be plane, may be taken in that plane; and q_1, . . . q_n are quaternions, which in the special case just mentioned are powers of one quaternion in the same plane. We obviously have, if $\mathrm{D}q_r = q_{r+1}$ for the plane polygon, two conditions:—the first,

$$(1 + \mathrm{D} + \mathrm{D}^2 + \ldots + \mathrm{D}^{n-1})q_r\alpha = 0\,,$$

depending on our choice of origin; and the second,

$$\frac{1}{2^m}(1 + \mathrm{D})^m q_r\alpha = \mathrm{Q}\mathrm{D}^s q_r\alpha\,,$$

depending on the similarity of the m^{th} derived polygon to the original. In this last equation, Q is a scalar multiple of an unknown power of the quaternion of which the qs are powers, expressing how the original polygon must be turned in its own plane, and how its linear dimensions must be altered, so that it may be superposed on the m^{th} derived polygon. Also s is an unknown integer, but it has (like Q) a definite value or values when the problem admits of solution. r has *any* value from 1 to n inclusive, as may be seen at once by operating by any integral power of D, and remembering that we have necessarily

$$\mathrm{D}^n q_r = q_r\,.$$

The solution of this case is easily effected, and gives the well-known results:—the general solution involving all equilateral and equiangular polygons, where m may have any integral value. Besides this, there are special solutions for the triangle, and quadrilateral reduced at one operation to a parallelogram. In the former of these m may have any value; in the latter (unless the figure be a square) m must be even.

But, when the polygon is gauche, the second of the above conditions becomes

$$\frac{1}{2^m}(1+D)^m q_r a = QD^s q_r a Q^{-1},$$

and the solution is somewhat more difficult. Its interest consists in its leading to a new and curious question in quaternions.

5. On Vortex Motion. By Professor Tait.

(*Abstract.*)

This paper contained a discussion of the consequences of the *assumption* of continuity of motion throughout a perfect fluid; one of the bases of von Helmholtz's grand investigation, on which W. Thomson founded his theory of vortex-atoms. It is entirely on the assumed absence of finite slip that von Helmholtz deduces the action of a rotating element on any other element of the fluid, and that Thomson calculates the action of one vortex-atom or part of such an atom on another atom, or on the remainder of itself. The creation of a single vortex-atom, in the sense in which it is defined by Thomson, involves action applied simultaneously to all parts of the fluid mass, not to the rotating portion alone.

Monday, 3rd March 1884.

Sir WILLIAM THOMSON, F.R.S., Vice-President, in the Chair.

The Council having awarded the Keith Prize for the Biennial Period 1881–83 to Mr Thomas Muir, for his Researches into the Theory of Determinants and Continued Fractions, the most recent instalment of results obtained by him being in a Paper on "Permanent Symmetric Functions," the Chairman presented the prize.

Professor Chrystal, in explaining the grounds of the award, said —While it would be easy to give you an idea of the manner of man whom the Society has delighted to honour, I feel that the task imposed upon me by your Council of giving the members at large some idea of the actual work for which the Keith Prize has in this instance been awarded is a difficult one.

Were the subject of my discourse a physicist, a geologist, or even a biologist, I might tell you of the mills that would be turned by means of his discoveries, of the kinds of coal or of diamond to

be explored under his leadership, or I might take your fancy a promenade on that most fascinating new pleasure-ground of naturalists, the bottom of the sea.

But, in the case of a pure mathematician's work there is, to use the words of one of the greatest living cultivators of the analytic art, no such appeal to the immediate Utilitarianism so dear to the Philistine soul. If, however, the public to whom I can appeal is small, I feel that their judgment is sure; and, when I have reminded those who represent that public here, of the succession of papers which Mr Muir has contributed to our *Transactions* and *Proceedings*, I am confident that they will sanction with an emphatic approval the decision of the Council of the Royal Society to confer upon him the Keith Prize.

One of the most interesting branches of analysis is the theory of Continued Fractions. The subject has a double interest, because it is connected on the one hand with that most pure of all the branches of pure mathematics, I mean the theory of numbers, a sanctuary into which the profane foot of even the applied mathematician scarcely enters; and, on the other, with the theory of forms, for I need scarcely remind my mathematical hearers that the algorithms of the greatest common measure and of the calculation of the convergent to a continued fraction are formally identical; and that this algorithm is also that by which Sturm deduced the functions which bear his name, and which play so important a part in the theory of equation.

Mr Muir has pursued the theory of continued fractions, and has obtained some very important results in both its branches.

In the first paper of the series for which the Keith Prize is now awarded him, published in the twenty-seventh volume of our *Transactions*, he gives a perfectly general solution of the problem of transforming an infinite series into a continued fraction. Special cases of this transformation were known before, but no one had been able to assign the general form of the expression until Mr Muir successfully attacked the problem.

His second paper, in volume xxviii. of the *Transactions*, is to my mind the most noteworthy of the various pieces of work now under review. He there takes up a number of remarkable transformations of various series into the form of continued fractions, which were

given by the great but prematurely removed mathematician Eisenstein. These results of Eisenstein's were left by him almost entirely without demonstration, and their connection among themselves or with other known theorems was very obscurely indicated. So much was this the case, that several mathematicians had endeavoured unsuccessfully to prove the truth or falsity of the results.

Mr Muir, guided mainly by the general ideas gained in the research just mentioned, takes up these theorems of Eisenstein's, and succeeds with apparent ease in not only proving them, but in showing their relation to each other and to other known results.

There is yet another of Mr Muir's papers on the subject of continued fractions which deserves especial mention at this moment. I allude to his paper on Continuants, in the eighth volume of the Society's *Proceedings.* Passing over the remarkable general theorems regarding the special form of determinants called continuants, I would especially direct your attention to the remarkable theorems there arrived at regarding the expression of quadratic surds by means of continued fractions. Mr Muir finds a general expression for any integer whose square root is expressible by means of a continued fraction having unit numerators and a given recurring cycle of denominators. And he finds the general condition, that any given periodic fraction may represent a quadratic surd.

Another branch of analysis in which Mr Muir has equally distinguished himself is the theory of Determinants, which I may call the chief handmaiden of the theory of algebraic forms. In this subject Mr Muir may be classed as a worthy follower of our great countrymen, Sylvester and Cayley. I need only allude at present to three of the papers on this subject. The papers in volumes xxix. and xxx. of the *Transactions* contain two most valuable generalisations in this theory, viz., Mr Muir's Extension of Laplace's Law, and his Theorem of Extensible Minors. These results are characteristic of Mr Muir's work, the constant tendency of which is the attainment of that higher kind of simplicity which results from greater generalisation.

Concerning the last paper of the series (not, I am glad to see by the evidence of the billet for to-night, the last from Mr Muir to the Society), On a Class of Permanent Symmetric Functions, I have simply to say, that in it, by the evolution of a few simple general

theorems, Mr Muir succeeds in drawing together into a compact whole a series of highly interesting but hitherto isolated results.

The Council having awarded the Makdougall-Brisbane Prize for the period 1880–82 to Professor James Geikie, for his contributions to the Geology of the North-West of Europe, including his Paper on the Geology of the Faröes, published in the *Transactions* of the Society, 1880–81, the Chairman presented the prize.

Lord Maclaren, in explaining the grounds of the award, said —The Council has awarded the Makdougall-Brisbane Prize to Professor James Geikie for his contributions to the geology of the north-west of Europe, including his paper on the "Geology of the Faroes," published in the *Transactions* of this Society.

The Society does not need to be informed of Professor Geikie's contributions to geological literature, because—like the great geologists of the Scottish school—our professor is able to invest his scientific writings with the charm of a flowing and picturesque literary style, and his works descriptive of the Great Ice Age and of the later Prehistoric Period, when man appears upon the scene in the company of the mammoth and cave-bear, have been perhaps as widely read as those of his distinguished compatriots Charles Lyell, Hugh Miller, and Roderick Murchison.

But it is not only for their descriptive merits that the writings of our prizeman-elect claim our recognition. In his first and perhaps most important work, Professor Geikie proposed to himself the task of exhibiting the causes of that most remarkable and indubitable phenomenon, the existence of continuous traces of ice-action throughout an area which extends laterally over all the elevated land of the north-west of Europe, and vertically from the highest mountain peaks to the water lines of our European shores and valleys.

I will not undertake to say whether the bold conception of an ice-cap or ice-river stretching from the Arctic Circle to the alluvial plains of England and Germany originated in the mind of our distinguished friend, or whether it was suggested by the discoveries in connection with the ice-cap of another planet whose polar surface is said to be already better known to science than that of our own world. But whether the idea of a northern ice-cap was or was not in the air, to Professor Geikie belongs the merit of having subjected that idea to the test of a rigorous scientific examination, and of hav-

ing collected and marshalled a most imposing array of facts and logical deductions in support of his theory. I do not need to remind the Society of the confirmation which his views have received from the results of the expedition of last summer to the interior of Greenland, which are the more remarkable that Baron Nordensjöld went to Greenland in the design of *disproving* the existence of a continental ice-cap in that region, and returned convinced of its existence by the evidence of his own eyes and the reports of his explorers.

Professor Geikie, I suppose, has not penetrated so far north, but we know that he has qualified himself for the exposition of the history of the Glacial Age by a careful study of all its phenomena, not only in Scotland, for which his connection with the Geological Survey offered peculiar facilities, but also on the Continent of Europe, and among the islands of the North Atlantic. Of these studies his published works, as well as his contributions to the transactions of scientific societies, offer ample evidence. His latest contribution is the paper on the Faroes, which appears in the *Transactions* of this Society. In estimating the importance of that paper, it may be remarked that the geological interest of a country or group of islands, is not to be measured by their political and commercial importance. In this paper we find evidence that the Faroes have been covered by an ice-cap or *mer de glace* of 1400 feet in thickness, entirely local in its origin. The fact that ice has accumulated to so great a height in this relatively small area, makes the geological evidence applicable to the greater and more elevated ice-masses of the continent more significant, and perhaps more easy of reception and comprehension. I have no doubt the Society will approve of the nomination of Professor Geikie by the Council for the Makdougall-Brisbane Prize.

The Council having awarded the Neill Prize for the Triennial Period 1880–83 to Professor Herdman, for his Papers in the *Proceedings* and *Transactions* on the Tunicata—

Mr John Murray, in explaining the grounds of the award, said —Professor Herdman's principal papers on the Tunicata may be divided into two groups,—1st, those on British Ascidians, and 2nd, those on the collections made during the "Challenger" expedition.

In his first paper,* "Notes on British Tunicata," published in 1880, a suggestion is made as to the cause of the peculiar relations of the viscera in the genera *Ascidia*, *Ciona*, and *Corella*. Six new species are described, and several old ones are fully described for the first time, and their synonymy cleared up. In subsequent papers † on British Ascidians, various other species are described, and he deals with individual variations in the Tunicata, traces changes in the branchial sac of *Styela grossularia*, showing the folds becoming obsolete and almost disappearing,‡ discusses the variations of the dorsal tubercle within the limits of species, and tries to show how the various forms are connected.§

In the last number of the *Transactions* there is a paper on the "Tunicata of the Faroe Channel," in which the anatomy and histology of *Doliolum* is treated in great detail.

The valuable collections made by the "Challenger" Expedition were placed in Professor Herdman's hands for examination and description, and the preliminary notices of these were published in the *Proceedings* of this Society. In the first part of the final Memoir published in the "Challenger" series of Reports, nine new genera and seventy-four new species are described.

If we except the Molgulidæ, which Lacaze-Duthiers discussed in 1877, Professor Herdman was the first to fully define the families and sub-families of the *Ascidiæ Simplices*.

The anatomy and histology of the new and more remarkable deep-sea forms are described in great detail, the description of *Culeolus murrayi* being probably the most minute and detailed description of an Ascidian that has ever been published.

In this memoir some remarkable structures are for the first time pointed out,—1st, a system of branched calcareous spicules in the vessels of the branchial sac and endostyle; 2nd, a curious modification of the blood-vessels in the test, which probably converts the outer layer of the latter into a respiratory organ. The family Clavelinidæ is removed from the compound to the simple Ascidians, and reasons are given for this change in classification, and the Report concludes with a phylogenetic table.

* *Journ. Linn. Soc. Zool.*, vol. xv. p. 274.

† *Ibid.*, p. 329.

‡ *Proc. Lit. and Phil. Soc.*, Liverpool.

§ *Proc. Roy. Phys. Soc.*, Edinburgh.

In 1881 Julin and E. van Beneden proposed the homology of the neural gland in the Tunicata with the vertebrate pituitary body. Professor Herdman has suggested a modified theory—that the neural gland, its duct, and the dorsal tubercle (and therefore also the original pituitary body) were formed by the conjunction of a primitive renal organ and a sense organ.

Some of Professor Herdman's views have been subjected to considerable criticism by continental biologists, but it is universally acknowledged that his remarkable series of papers on the Tunicata are characterised by great ability, and the Council have accordingly adjudged to Professor Herdman for these papers the Neill Medal.

The following Communications were read :—

1. On Efficiency of Clothing for maintaining Temperature. By Sir W. Thomson.

2. On the Law of Inertia; the Principle of Chronometry; and the Principle of Absolute Clinural Rest, and of Absolute Rotation. By Professor James Thomson, LL.D., D.Sc., C.E.

There is no distinction known to men among states of existence of a body which can give reason for any one state being regarded as a state of absolute rest in space, and any other being regarded as a state of uniform rectilinear motion. Men have no means of knowing, nor even of imagining, any one length rather than any other, as being the distance between the place occupied by the centre of a ball at present, and the place that was occupied by that centre at any past instant; nor of knowing or imagining any one direction, rather than any other, as being the direction of the straight line from the former place to the new place, if the ball is supposed to have been moving in space. The point of space that was occupied by the centre of the ball at any specified past moment is utterly lost to us as soon as that moment is past, or as soon as the centre has moved out of that point, having left no trace recognisable by us of its past place in the universe of space.

There is then an essential difficulty as to our forming a distinct

conception either of rest or of rectilinear motion through unmarked space.

We have besides no preliminary knowledge of any principle of chronometry, and for this additional reason we are under an essential preliminary difficulty as to attaching any clear meaning to the words *uniform rectilinear motion* as commonly employed, the uniformity being that of equality of spaces passed over in equal times.

If two balls are altering their distance apart, we cannot suppose that they are both at rest. One, at least, must be in motion.

Men have very good means of knowing in some cases, and of imagining in other cases, the distance between the points of space simultaneously occupied by the centres of two balls; if, at least, we be content to waive the difficulty as to imperfection of our means of ascertaining or specifying, or clearly idealising, simultaneity at distant places. For this we do commonly use signals by sound, by light, by electricity, by connecting wires or bars, and by various other means. The time required in the transmission of the signal involves an imperfection in human powers of ascertaining simultaneity of occurrences in distant places. It seems, however, probably not to involve any difficulty of idealising or imagining the existence of simultaneity. Probably it may not be felt to involve any difficulty comparable to that of attempting to form a distinct notion of identity of place at successive times in unmarked space.

There is, in the nature of things, a real distinction, cognisable by men, between absolute rotation (or absolute clinural motion) and absolute freedom from rotation (or absolute clinural rest).*

The only motion of a point that men can know of or can deal with is motion relative to one, two, three, or more other points. Three points marked or indicated on one, two, or three bodies, the centres, for instance, of three balls, whether preserving their distances apart, unchanging or not, are sufficient for enabling us to construct or to imagine a reference frame of any changeless configuration desired—three rectangular co-ordinate axes, for instance, or

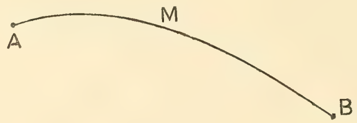
* The word *clinural* is to be understood as introduced for conveying precisely one out of the various conflicting meanings of the word directional. All straight lines which are mutually parallel are, in this amended mode of nomenclature, said to be in one same *clinure*. In connection with this, it may be convenient here to mention that all parallel planes are, in like manner, said to be in one same *posure*.

three rectangular co-ordinate planes—to which the situations, instantaneous or successive, of points may be referred.

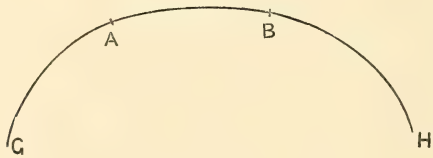
Any arrangement whatever of points, lines, or planes, changeless in mutual configuration, will, for present purposes, be named as a reference frame, or briefly as a *frame.*

The word *motion*, in ordinary usages, has several varied significances.

1. Thus it is often said that a body, or rather some specified point of it, has performed a motion from a point A to a point B, along a straight or curved line of motion AMB. It may be often said that this same motion has been effected slowly on one occasion and quickly on another, speed or velocity of the moving point not being treated as any essential quality or condition of the motion.



2. Again, it is often said that a point, moving along a curve GABH, has a certain motion at the instant of its passing A, and that its motion undergoes change during the passage from A to B, and that at B it has a motion changed from that which it had at A. In this sense the motion at A is regarded as determined by the line of motion specified as being the tangent to the curve at A, and the



ward, or way, of the motion along its line at the point of contact A, and the velocity of the motion at that point. The velocity of the motion is usually understood as meaning a true time rate of motion —a rate which may be specified, for instance, as being that of so many feet per second, or the like. For this ordinary mode of specifying that which is to be called velocity, it is necessary that

true chronometry should have been previously attained to, in idea at least, and approximately in fact.

Sometimes it is found convenient to apply, temporarily at least, the name *velocity* (for want of any other name) to the rate of travel of a point along a line as referred to the progress of something else moving relatively to a frame or to a dial. Thus, for a point moving along a line, the motion at any point of the path may sometimes be said to have a velocity of so many feet per unit of angular space turned by the crank shaft of a steam engine relatively to the framing of the steam engine. What is thus specified might be called a *quasi-velocity*, not a *true velocity*, as it is customary to regard true velocity as being referred not to the revolution of a steam engine shaft, nor to the revolution of a hand of a badly-going clock, but to the progress of absolutely true time when once the idea of progress of true time has been arrived at.

Before arriving at any principle of absolute chronometry, however, we cannot deal with true velocity at all. We cannot specify a rate of progress of any moving point relatively to progress of true time, or relatively to progress of a clock hand on its dial advancing proportionally to progress of true time. But, without assuming or presupposing any principle of absolute chronometry, we can refer motions of points to an assumed reference frame, jointly with an assumed dial-traveller. The dial-traveller may conveniently be imagined as a clock hand or index travelling continuously along a graduated dial, such as the face of a clock, but without the adaptation of any pendulum or balance wheel, or other chronometric arrangement for regulating the motion of the hand. The traveller, for instance, might be kept moving round its dial by a winch handle, such as that of a grindstone, or of a barrel organ, turned by hand. Or it might be an index projecting out radially from the crank shaft of a steam engine, and revolving round a dial fixed to the adjacent framework of the engine, so as to surround the shaft. Or the traveller might be an index kept revolving by the shaft of a water wheel, with a motion depending on variable conditions of rain-fall and stream-flow.

For purely kinematic considerations as to relative motions of points or bodies we have no essential concern with true time, nor with true velocities, understood as velocities of motions relative to a frame, and specified quantitatively as true time rates.

Now, reverting to the essential difficulty already mentioned as to our forming a distinct conception either of rest or of uniform rectilinear motion, we may go forward to some further considerations and scrutinies as to what men can imagine or can really know through observation and experience respecting motions of bodies in the universe of space.

We may have a firm persuasion, even without perfect understanding, that in the nature of things there must be a reality corresponding to our glimmering idea of motion of a body along a straight course with changeless velocity, and that there must be an essential distinction between such motion and motion along a curved course or motion with varying velocity. We cannot, however, specify such motions relatively to unmarked space and unmeasured passage of time. We cannot specify them as to any condition of absolute rest. We can only specify them as to part of their characters, or conditions, or distinctions. We can do so only in so far as qualities or distinctions of motions of one or more bodies can be ascertained through knowable relations between these motions and the motions of one or more other bodies. Briefly, we can deal only with relative motions or relative rest; not with absolute motions nor absolute rest.

Sir Isaac Newton sets forth, under the designation of the First Law of Motion, the statement that—*Every body continues in its state of resting or of moving uniformly in a straight course, except in so much as, by applied forces, it is compelled to change that state.*

A most important truth in the nature of things, perceived with more or less clearness, is at the root of this enunciation, but the words, whether taken by themselves or in connection with Newton's prefatory and accompanying definitions and illustrations, are inadequate to give expression to that great natural truth. In attempting to draw from the statement a perfectly intelligible conception, we find ourselves confronted with the preliminary difficulty or impossibility as to forming any perfectly distinct notion of a meaning in respect to a single body, for the phrase "*state of resting or of moving uniformly in a straight course.*" Newton's previous assertion *that there exists absolute space which, in its own nature, without reference to anything else, always remains alike and immovable,* does not clear away the difficulty. It does not do so, because it involves

in itself the whole difficulty of our inability to form a distinct notion of identical points or places in unmarked space at successive times, or of our inability to conceive any means whatever of recognising afterwards in any one point of space, rather than in any other, the point of space which, at a particular moment of past time, was occupied by a specified point of a known body.

To aid in the apprehension of the underlying truth referred to, and also as an aid to the understanding of the enunciation about to be given in the present paper as *The Law of Inertia* and *Principle of Chronometry*, some purely kinematic principles will now be adduced for consideration. Thus the question is to be opened up as to what may be the nature of relative motions of various bodies, which can in any sense truly be regarded as uniform rectilinear mutual motions. Explanations are to be given *on such motions of points in unmarked space, as can have a reference frame and reference dial-traveller relatively to which jointly those motions are rectilineanar and are uniform in the sense of being changeless in quasi-velocity.* In other words, quite to the same effect—Explanations are to be given *on such motions of points in unmarked space as can have a reference frame relatively to which those motions are rectilinear and are changeless in mutual rate; or what is the same, are mutually proportional in their simultaneous progress.*

Let us imagine a reference frame, rigid in its configuration, and for simplicity let it be taken as including three rectangular reference planes firmly connected. Let several points or small bodies be kept moving by geared mechanism, such as that of toothed wheels on variously inclined axles, and toothed straight sliding racks with pinions, all carried or guided in bearings firmly attached to the reference frame, the arrangements being such that those moving points shall be made simultaneously to travel over mutually proportional lengths along straight lines fixed in relation to the reference frame. The motion may be given by a winch handle like that of a barrel organ, fixed on one of the axles; and, for help in consideration of the subject, we may imagine a uniformly graduated dial surrounding the winch handle axle, and an index attached to the axle so as to project radially outwards like a hand of a clock, and to travel round the dial keeping pace in angular motion with the winch handle. Thus the simultaneous travels of the various

small bodies along their straight courses are to be mutually proportional, and they are also to be proportional each of them to the simultaneous travel of the index on the dial. Now, if any other frame of three co-ordinate planes be arranged to exist with the point of their intersection keeping at any one of the moving points, and with the three planes maintaining changeless angles with the original three reference planes, any one of the moving points will either be at rest relatively to the new set of reference planes, or will generate, in relation to them, a straight line, and the simultaneous lengths traversed by the various points relatively to these new reference planes will be mutually proportional. It is convenient to notice, in preparation for subsequent reference of motions to true time or to a truly chronometric clock, that the simultaneous lengths traversed by the various points relatively to the new reference planes, and of the winch handle index relatively to its dial, will be mutually proportional. We may thus see that for the established set of motions of the points, there can exist as many sets of reference planes or frames as we please, differently moving and differently inclined, in reference to each of which every one of the points will generate a straight line with a quasi-velocity (or rate per dial-traveller progress) proportional to the quasi-velocity of every other along its own line. We are now perfectly entitled to speak of the motions of all these points as referred to any one of the frames and the original dial-traveller, as being uniform rectilinear motions. The word uniform, it should be noticed, has, neither in its origin nor in its customary employment, any essential connection with progress of time. The notion besides of the dial-traveller as a standard to which the simultaneous travels of the various points may conveniently be referred, or rated, is not at all essential. We would be quite entitled, without knowledge of chronometry, and without having recourse to the quasi-time indicated by the dial-traveller, to speak of the motions of all the points relatively to all the reference frames, as being uniform rectilinear motions. The uniformity in rate of progress would be in respect to rate of travel of any one of the points per simultaneous travel of any other one of them. In all that has been said in this matter no assumption has been made as to any particular condition of rest or motion having belonged to the original reference frame. It may have been firmly

attached to the surface of the earth, or it may have been firmly attached to the floor and side walls of the cabin of a ship sailing in devious courses over the sea and tossing on the waves. Notwithstanding any such motions, or any motions whatever, belonging to the original reference frame, the mutual motions of the points will possess the character that they admit of having reference frames, as many as we please, relative to which they will be rectilinear and mutually proportional (or, in other words, they will be uniform rectilinear motions, by mutual reference without reference to time). If the moving points alone were available to us for progressive observation or measurement it might be a difficult, perhaps an extremely difficult, geometrical or kinematical problem* to find from them a reference frame accomplishing the stated condition; but this does not hinder us from easily and distinctly understanding that such a frame is geometrically or kinematically possible. On the other hand, for a set of points moving at random like flies in the air, or for a set of points having uniform rectilinear motion as already described, together with others revolving like satellites round some of them, no reference frame to accomplish the conditions stated would be possible. For a single fly moving anyhow, reference frames would be possible, relative to any one of which the motion of the fly would be rectilinear, and would be uniform in rate of progress relatively to true time, or to any assumed standard whatever for rate of progress; but for two flies, or any greater number, no such frame would be possible. Reasons for this are so obvious as scarcely to require statement. Briefly, however, it may be mentioned that any two flies might in their mutual motions come into contact once and then separate, and then come into contact again; but no second meeting could occur with points moving

* *Postscript Note, May* 1884.—On the evening of the reading of the paper (March 3, 1884), just after the close of the meeting of the Society, the author inquired of Professor Tait whether he could see how the problem referred to here in the paper as being perhaps extremely difficult, could be solved. Professor Tait replied that he could solve it very briefly by use of quaternions. The author, not being at all acquainted with quaternions, has since seen his way clearly to the solution by an easy method of mechanical adaptations. The mechanical method is merely for intellectual use, not for practical application. The ideal mechanism can serve as an instrument for use in reasoning, though friction, and elasticity of materials, &c., might render it incapable of complete practical realisation.

straightly and mutually proportionally in relation to any frame whatever. Or the two flies might be increasing their distance apart and afterwards diminishing it; but no approach after recession is possible for points moving straightly and proportionally in relation to any frame whatever.

The explanations now given are sufficient to show that there can be mutual motions of various bodies, so related as to have a property of being uniform rectilinear mutual motions, and to explain the nature of that mutual relation. This is quite irrespective of any idea of chronometry, or any idea of absolute rest or motion in the universe, or of any idea of absolute clinural rest or absolute rotation, and of any distinction whereby one body might be said to be in absolute rotation and another devoid of absolute rotation. The mutual relation described has been purely kinematic, and will not be at all altered by the superposition of any new motion whether of translation or of rotation, the meaning of this statement being rendered intelligible by consideration of the attachment of the original reference frame to the floor and side walls of the cabin of a ship at sea, already mentioned.

Now, to pass from mere geometric or kinematic motions, governed mutually by connecting mechanism to the motions of bodies existing in space free from any such governance, we are to accept as an established law of nature, established through multitudinous observations and speculations, together with theories confirmed by multitudinous agreements, the following, which may be called the law of inertia.

The Law of Inertia.

For any set of bodies acted on each by any force, a REFERENCE FRAME and a REFERENCE DIAL-TRAVELLER are kinematically possible, such that relatively to them conjointly, the motion of the mass-centre of each body, undergoes change simultaneously with any infinitely short element of the dial-traveller progress, or with any element during which the force on the body does not alter in direction nor in magnitude, which change is proportional to the intensity of the force acting on that body, and to the simultaneous progress of the dial-traveller, and is made in the direction of the force.

Principle of Chronometry.

From the foregoing law it is readily deducible, as a corollary by elementary mathematical considerations, that—

Any dial-traveller which would accomplish the conditions stated would make progress proportionally with any other dial-traveller, obtained likewise from the same set of bodies, or any other set of bodies with the same or any other reference frame. Then, in view of this remarkable agreement, we define as being equal intervals of time, or we assume as being somehow in their own nature intrinsically and necessarily equal intervals of time, the intervals during which any such dial-traveller passes over equal spaces on its dial. Thus, any dial-traveller which would accomplish the conditions stated would constitute a perfect chronometer.

This gives us the ideal of a perfect chronometer. It remains for men to aim at approaching as near as they can towards that ideal in the practical realisation of good chronometry.

For good and long-enduring realisations of chronometry, astronomical methods are alone available. None of these present any simple method of procedure. They require hypothetical assumptions of supposed forces acting on the bodies considered, and, above all, there is involved in them the assumption, and after multitudinous tests, accompanied by multitudinous confirmations, the discovery of the Law of Universal Gravitational Attraction—the grandest of the discoveries of Sir Isaac Newton.

Principle of Absolute Clinural Rest and of Absolute Rotation.

Any straight line fixed relatively to any reference frame which accomplishes the conditions specified in the statement of the law of inertia has absolute clinural rest. If another straight line fixed in any other such reference frame be parallel to that former line, the two lines will continue parallel, so that by either of them the one same absolute clinure is permanently preserved. The principle here called that of absolute clinural rest is clearly enunciated in Thomson and Tait's *Natural Philosophy*, § 249, under the designation of "Directional Fixedness." It is there exhibited by a very simple device, and here by a somewhat different method.

Any body which has no rotation relative to a framing which accomplishes the conditions stated is devoid of absolute rotation, and if a body rotates relatively to any such frame it has the same rotation absolutely.

The Law of Inertia here enunciated sets forth all the truth which is either explicitly stated or is suggested by the First and Second Laws in Sir Isaac Newton's arrangement.

By applying the Law of Inertia to the case in which the forces acting on the bodies vanish, the law becomes a remodelled substitute for the statement set forth by Sir Isaac Newton as the First Law of Motion in his arrangement.

3. On a Modification of Gauss's Method for determining the Horizontal Component of Terrestrial Magnetic Force, and the Magnetic Moments of Bar Magnets, in Absolute Measure. By Sir W. Thomson.

4. On the Phenomenon of "Greatest Middle" in the Cycle of a Class of Periodic Continued Fractions. By Thomas Muir, M.A.

1. The highest square in an integer H being A^2 and

$$H = A^2 + D,$$

it is a familiar fact that the square root of H when expressed in the ordinary way as a continued fraction with unit-numerators takes the form

$$A + \frac{1}{\overset{*}{q_1}} + \frac{1}{q_2} + \cdots + \frac{1}{q_2} + \frac{1}{q_1} + \frac{1}{\overset{*}{2A}} + \frac{1}{q_1} + \cdots$$

the last element of the cycle of partial quotients being double the unique partial quotient A, and the cycle without this last element being the same when read backwards as when read forwards. It is also known that in the symmetric portion of the cycle no element

can be greater than A, and that an element equal to A can occur in only one position, viz., in the middle of the cycle. Thus—

$$\sqrt{31} = 5 + \frac{1}{\underset{*}{1}+}\frac{1}{1+}\frac{1}{3+}\frac{1}{5+}\frac{1}{3+}\frac{1}{1+}\frac{1}{1+}\frac{1}{\underset{*}{10}+}\dots$$

This is the phenomenon of "greatest middle." For convenience we may call a cycle in which it appears a *culminate* cycle. With such cycles several very interesting theorems are connected.

2. *The necessary and sufficient condition that the middle element* q_z *of the cycle of partial quotients shall be equal to the unique partial quotient is*

$$(q_2 \dots q_{z-1}) = 2(q_1 \dots q_{z-2}) .$$

Whether the cycle be culminate or not, it is known that

$$\frac{(A, q_1 \dots q_{z-1})\{(A \dots q_{z-2}) + (A \dots q_z)\}}{(q_1 \dots q_{z-1})\{(q_1 \dots q_{z-2}) + (q_1 \dots q_z)\}} = H$$

and as $(A \dots q_{z-1})$ and $(q_1 \dots q_{z-1})$ are mutually prime and their co-factors can have no common divisor except 2, it follows that

$$\frac{(A, q_1, \dots q_{z-1})}{(q_1 \dots q_z) + (q_1 \dots q_{z-2})} = \text{an integer} = J \text{ say.}$$

But $\quad (A, q_1, \dots q_{z-1}) = A\,(q_1, \dots, q_{z-1}) + (q_2, \dots, q_{z-1}),$

and $\quad (q_1 \dots q_z) = q_z(q_1, \dots, q_{z-1}) + (q_1, \dots, q_{z-2})\,;$

therefore in the case of "greatest middle" we have

$$\frac{2A(q_1, \dots, q_{z-1}) + 2(q_2, \dots, q_{z-1})}{A(q_1, \dots, q_{z-1}) + 2(q_1, \dots, q_{z-2})} = J\,;$$

$$\text{i.e. } 2 + \frac{2(q_2, \dots, q_{z-1}) - 4(q_1, \dots, q_{z-2})}{A(q_1, \dots, q_{z-1}) + 2(q_1, \dots, q_{z-2})} = J\,.$$

The numerator here, however, being less than the denominator,—for even $2(q_2 \dots q_{z-1})$ is less—must be zero, and therefore

$$(q_2, \dots, q_{z-1}) = 2(q_1, \dots, q_{z-2}) .$$

Conversely, if we suppose this to be the case, we can by taking the same starting-point show that $q_z = A$, that is, that the cycle is one of greatest middle.

The condition is thus necessary and sufficient.

3. *If* $\sqrt{A^2+D}$ *be expressed as a continued fraction with unit numerators, and the middle element* q_z *of the cycle of partial quotients be equal to* A, *then*

$$D = \frac{2(q_2, \ldots, q_{z-1}, A)}{(q_1, \ldots, q_{z-1})}.$$

We have already seen that generally

$$H = \frac{(A, q_1, \ldots, q_{z-1})\{(A, \ldots, q_{z-2}) + (A, \ldots, q_z)\}}{(q_1, \ldots, q_{z-1})\{(q_1, \ldots, q_{z-2}) + (q_1, \ldots, q_z)\}};$$

and J in the preceding paragraph being shown to be 2, we have in the case of "greatest middle,"

$$(A, q_1, \ldots, q_{z-1}) = (q_1, \ldots, q\ ) + (q_1, \ldots, q_{z-2}).$$

Hence

$$\begin{aligned} H(q_1,\ldots,q_{z-1}) &= (A,\ldots,q_{z-2}) + (A,\ldots,q_z) \\ &= 2A(q_1,\ldots,q_{z-2}) + (q_2,\ldots,q_{z-2}) + A^2(q_1,\ldots,q_{z-1}) + (q_2,\ldots,q_{z-1},A) \\ &= A(q_2,\ldots,q_{z-1}) + (q_2,\ldots,q_{z-2}) + A^2(q_1,\ldots,q_{z-1}) + (q_2,\ldots,q_{z-1},A) \\ &= (q_2,\ldots,q_{z-1},A) + A^2(q_1,\ldots,q_{z-1}) + (q_2,\ldots,q_{z-1},A) \\ \therefore H &= A^2 + \frac{2(q_2,\ldots,q_{z-1},A)}{(q_1,\ldots,q_{z-1})}, \end{aligned}$$

as was to be proved.

4. *The condition* $(q_2, \ldots, q_{z-1}) = 2(q_1, \ldots, q_{z-2})$ *being satisfied, the general expression for all integers whose square roots have culminate cycles is*

$$[(q_1,\ldots,q_{z-1})M - (q_1,\ldots,q_{z-2})(q_2,\ldots,q_{z-2})]^2 + (-1)^z\{4(q_1,\ldots,q_{z-2})M - 2(q_2,\ldots,q_{z-2})^2\}.$$

From § 3 we have

$$\begin{aligned} D &= \frac{2(q_2, \ldots, q_{z-1}, A)}{(q_1, \ldots, q_{z-1})} \\ &= \frac{2A(q_2, \ldots, q_{z-1}) + 2(q_2, \ldots, q_{z-2})}{(q_1, \ldots, q_{z-1})} = \frac{2AQ_{z-1} + 2Q_{z-2}}{P_{z-1}} \text{ say.} \end{aligned}$$

Multiplying both sides by P_{z-2} and using the identity

$$P_{z-1}Q_{z-2} - P_{z-2}Q_{z-1} = (-1)^{z-1}$$

we have

$$\begin{aligned} P_{z-2}D &= \frac{2A\{P_{z-1}Q_{z-2} - (-1)^{z-1}\} + 2P_{z-2}Q_{z-2}}{P_{z-1}}, \\ &= 2AQ_{z-2} + \frac{(-1)^z 2A + 2P_{z-2}Q_{z-2}}{P_{z-1}}. \end{aligned}$$

Now as (§ 2) Q_{z-1} is even, P_{z-1}, which is prime to it, is odd; hence

$$\frac{(-1)^z A + P_{z-2}Q_{z-2}}{P_{z-1}} = \text{an integer} = \text{M say.}$$

$$\therefore\ A = (-1)^z P_{z-1}\text{M} - (-1)^z P_{z-2}Q_{z-2} \quad . \quad . \quad . \quad . \quad (\alpha).$$

Substituting this in the expression for $P_{z-2}D$ we have

$$\begin{aligned} P_{z-2}D &= (-1)^z 2P_{z-1}Q_{z-2}\text{M} - (-1)^z 2P_{z-2}Q^2_{z-1} + 2\text{M} \\ &= (-1)^z 2\text{M}\{P_{z-1}Q_{z-2} + (-1)^z\} - (-1)\ 2P_{z-2}Q^2_{z-2} \\ &= (-1)^z 2\text{M}P_{z-2}Q_{z-1} - (-1)^z 2P_{z-2}Q^2_{z-2} \\ \text{and } \therefore\ D &= (-1)^z 2\text{M}Q_{z-1} - (-1)^z 2Q^2_{z-2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (\beta). \end{aligned}$$

As $H = A^z + D$ it is seen that (α) and (β) give the desired expression.

5. As an example of the use of the preceding result, let us try to find all the numbers whose square roots have culminate cycles of *eight* elements.

If we denote the symmetric portion of the cycle by

$$a,\ b,\ c,\ d,\ c,\ b,\ a,$$

the initial condition which we have to satisfy is

$$\begin{aligned} (b,\ c) &= 2(a,\ b)\,; \\ \textit{i.e.},\quad bc + 1 &= 2ab + 2\,; \\ \textit{i.e.},\quad b(c - 2a) &= 1\,; \end{aligned}$$

the solution of which in integers is clearly

$$b = 1, \text{ and } c = 2a + 1\,.$$

We thus have

$$\begin{aligned} P_{z-1} &= (a,\ 1,\ 2a+1) = 2a^2 + 4a + 1\,, \\ P_{z-2} &= (a,\ 1) \qquad\quad\ = a + 1\,, \\ Q_{z-2} &= 1\,; \end{aligned}$$

so that the general result desired is

$$\begin{aligned} &\sqrt{\{(2a^2 + 4a + 1)\text{M} - (a+1\}^2 + 4(a+1)\text{M} - 2} \\ &= \Big\{\quad\Big\} + \frac{1}{\underset{*}{a}} + \frac{1}{1} + \frac{1}{2a+1} + \frac{1}{\{\quad\}} + \frac{1}{2a+1} + \frac{1}{1} + \frac{1}{a} + \frac{1}{\underset{*}{2\{\quad\}}} + \cdots, \end{aligned}$$

where for shortness there is put

$$\{\quad\} \text{ for } \{(2a^2 + 4a + 1)\text{M} - (a+1)\}\,.$$

The only difficulty which lies in the way of finding the corresponding result for cycles of a greater number of elements is the solution in integers of the indeterminate equation—

$$(q_2, \ldots, q_{z-1}) = 2(q_1, \ldots, q_{z-2}).$$

This is the analytical problem we now attack.

6. *In a culminate cycle of* 2z *elements,* q_1, q_2, *&c., we have either*

$$q_{z-1} = 2q_1, \quad or \quad q_{z-1} = 2q_1 + 1;$$

and if the latter, then also $q_2 = 1$.

Since $(q_2, \ldots, q_{z-1}) = q_{z-1}(q_2, \ldots, q_{z-2}) + (q_2, \ldots, q_{z-3})$,
and $(q_1, \ldots, q_{z-2}) = q_1(q_2, \ldots, q_{z-2}) + (q_3, \ldots, q_{z-2})$;

therefore from the equation of condition we have

$$(q_{z-1} - 2q_1)(q_2, \ldots, q_{z-2}) = 2(q_3, \ldots, q_{z-2}) - (q_2, \ldots, q_{z-3}) \quad \ldots\ldots (\alpha).$$

Now

$$(q_2, \ldots, q_{z-2}) > (q_2, \ldots, q_{z-3}),$$
$$\therefore \quad q_{z-1} - 2q_1 \not< 0;$$

and

$$(q_2, \ldots, q_{z-2}) > (q_3, \ldots, q_{z-2}),$$
$$\therefore \quad q_{z-1} - 2q_1 \not> 1.$$

We have thus, as was to be shown, $q_z - 2q_1$ either $= 0$ or 1.

Further, when $q_{z-1} - 2q_1 = 1$, our equation (α) becomes

$$(q_2, \ldots, q_{z-2}) = 2(q_3, \ldots, q_{z-2}) - (q_2, \ldots, q_{z-3});$$
$$\therefore q_2(q_3, \ldots, q_{z-2}) + (q_4, \ldots, q_{z-2}) = 2(q_3, \ldots, q_{z-2}) - (q_2, \ldots, q_{z-3}) \quad \ldots. (\beta);$$

whence $q_2 < 2$,
and $\therefore$ $= 1$.

7. *In a culminate cycle of* 2z *elements, where* $q_{z-1} = 2q_1$, *the equation for determining the other elements is similar to the original equation of condition, being*

$$(q_2, \ldots, q_{z-3}) = 2(q_3, \ldots, q_{z-2}).$$

This follows at once from § 6 (α).

8. *In a culminate cycle of* 2z *elements where* $q_{z-1} = 2q_1 + 1$, if a *solution*

$$q_3, q_4, \ldots, q_{z-2} = a_3, a_4, \ldots, a_{z-2}$$

be found, then another solution is

$$q_3, q_4, \ldots, q_{z-2} = a_{z-2}, \ldots, a_4, a_3.$$

When $q_{z-1} = 2q_1 + 1$, we know that $q_2 = 1$; and therefore, from § 6 (β), the equation for determining the other elements is

$$(q_4, \ldots, q_{z-2}) = (q_3, \ldots, q_{z-2}) - (q_2, \ldots, q_{z-3})$$

i.e.,

$$= (q_3, \ldots, q_{z-2}) - (q_3, \ldots, q_{z-3}) - (q_4, \ldots, q_{z-3}).$$

or

$$(q_3, \ldots, q_{z-2}) = (q_3, \ldots, q_{z-3}) + (q_4, \ldots, q_{z-2}) + (q_4, \ldots, q_{z-3}).$$

Now the substitution here of $q_{z-2}, q_{z-3}, \ldots, q_4, q_3$ for $q_3, q_4, \ldots q_{z-3}, q_{z-2}$ respectively, changes the second of these continuants into the third, the third into the second, and does not alter the first and fourth; that is to say, the equation is symmetrical with respect to the two sets of quantities, which proves our theorem.

9. *In a culminate cycle of* 2z *elements where* $q_{z-1} = 2q_1 + 1$ *we have either*

$q_3 = 1$, *and* $(q_5, \ldots, q_{z-3}, q_{z-2} - 1) = 2(q_4, \ldots, q_{z-3})$,

or

$q_3 = 2$, $q_{z-2} = 2$, *and* $(q_4, \ldots, q_{z-3}) = (q_4, \ldots, q_{z-4}) + (q_5, \ldots, q_{z-3}) + (q_5, \ldots, q_{z-4})$,

or

$q_3 = 2 + \alpha$, $q_{z-2} = 1$, *and* $(1 + \alpha, q_4, \ldots, q_{z-4}) = 2(q_4, \ldots, q_{z-3})$.

From § 8 the equation for determining q_3, q_4, &c., is

$$(q_3, \ldots, q_{z-2}) = (q_3, \ldots, q_{z-3}) + (q_4, \ldots, q_{z-2}) + (q_4, \ldots, q_{z-3}).$$

This evidently gives

$$q_3(q_4, \ldots, q_{z-2}) + (q_5, \ldots, q_{z-2}) = q_3(q_4, \ldots, q_{z-3}) + (q_5, \ldots, q_{z-3}) + (q_4, \ldots, q_{z-2}) + (q_4, \ldots, q_{z-3}),$$

and $\therefore$

$$q_3 = \frac{(q_5, \ldots, q_{z-3}) + (q_4, \ldots, q_{z-2}) + (q_4, \ldots, q_{z-3}) - (q_5, \ldots, q_{z-2})}{(q_4, \ldots, q_{z-2}) - (q_4, \ldots, q_{z-3})}$$

$$= 1 + \frac{2(q_4, \ldots, q_{z-3}) + (q_5, \ldots, q_{z-3}) - (q_5, \ldots, q_{z-2})}{(q_4, \ldots, q_{z-2}) - (q_4, \ldots, q_{z-3})}$$

$$= 1 + \frac{2(q_4, \ldots, q_{z-3}) - (q_5, \ldots, q_{z-2} - 1)}{(q_4, \ldots, q_{z-2}) - (q_4, \ldots, q_{z-3})}.$$

Hence $q_3 = 1$, and $2(q_4, \ldots, q_{z-3}) = (q_5, \ldots, q_{z-2} - 1)$ is a partial solution.

Again, we may write

$$q_3 = 2 + \frac{3(q_4,\ldots,q_{z-3}) + (q_5,\ldots,q_{z-3}) - (q_4,\ldots,q_{z-2}) - (q_5,\ldots,q_{z-2})}{(q_4,\ldots,q_{z-2}) - (q_4,\ldots,q_{z-3})}.$$

Hence $q_3 = 2$, and $3(q_4,\ldots,q_{z-3}) + (q_5,\ldots,q_{z-3}) = (q_4,\ldots,q_{z-2}) + (q_5,\ldots,q_{z-2})$ is a partial solution. The second part of this, however, is advantageously carried farther. Thus we have from it

$$\begin{aligned} 3(q_4,\ldots, q_{z-3}) + (q_5, \ldots, q_{z-3}) = q_{z-2}(q_4, \ldots \qquad & + (q_4, \ldots, q_{z} -) \\ & + q_{z-2}(q_5, \ldots, q_{z-3}) + (q_5, \ldots, q_{z-4}) \end{aligned}$$

and $$\therefore \quad q_{z-2} = \frac{3(q_4 \ldots q_{z-3}) + (q_5, \ldots, q_{z-3}) - (q_4 \ldots q_{z-4}) - (q_5 \ldots q_{z-4})}{(q_4 \ldots q_{z-3}) + (q_5 \ldots q_{z-3})}$$

Now this fraction cannot $= 1$, for then we should have

$$2(q_4, \ldots, q_{z-3}) = (q_4, \ldots, q_{z-4}) + (q_5, \ldots, q_{z-4}),$$

which is impossible, for $2(q_4, \ldots, q_{z-3})$ is greater than either of the continuants on the right. Trying if it may equal 2, we put the result in the form

$$q_{z-2} = 2 + \frac{(q_4 \ldots, q_{z-3}) - (q_5 \ldots q_{z-3}) - (q_4 \ldots q_{z-4}) - (q_5 \ldots q_{z-4})}{(q_4 \ldots q_{z-3}) + (q_5 \ldots, q_{z-3})},$$

from which it is at once manifest that the only solution is

$$q_{z-2} = 2 \text{ and } (q_4 \ldots q_{z-3}) = (q_4 \ldots q_{z-4}) + (q_5 \ldots q_{z-3}) + (q_5 \ldots q_{z-4}).$$

Lastly, let us try if q_3 can be equal to $2 + \alpha$. We should then have

$$\begin{aligned} (3+\alpha)(q_4 \ldots q_{z-3}) + (q_5 \ldots q_{z-3}) &= (1+\alpha)(q_4 \ldots q_{z-2}) + (q_5 \ldots q_{z-2}), \\ &= (1+\alpha)q^{z-2}(q_4 \ldots q_{z-3}) + (1+\alpha)(q_4 \ldots q_{z-4}) \\ &\quad + q_{z-2}(q_5 \ldots q_{z-3}) + (q_5 \ldots q_{z-4}); \end{aligned}$$

$$\begin{aligned} \therefore \quad \{3+\alpha-(1+\alpha)q_{z-2}\}(q_4 \ldots q_{z-3}) = (1+\alpha)(q_4 \ldots q_{z-4}) + (q_{z-2} - 1)(q_5 \ldots q_{z-3}) \\ + (q_5 \ldots q_{z-4}). \end{aligned}$$

This necessitates

$$(3 + \quad) - (1+\alpha)q_{z-2} > 0;$$

$$\therefore \quad q_{z-2} < \frac{\alpha+3}{\alpha+1} < 1 + \frac{2}{\alpha+1}$$

and $$\therefore \quad q_{z-2} = 1$$

Putting $q_{z-2} = 1$, we see that we must further have

$$\begin{aligned} 2(q_4, \ldots, q_{z-3}) &= (1+\alpha)(q_4, \ldots, q_{z-4}) + (q_5, \ldots, q_{z-4}) \\ \text{i.e.,} \qquad &= (1+\alpha, q_4, \ldots, q_{z-4}), \end{aligned}$$

as was to be shown.

10. The theorems of the preceding four paragraphs, or even of §§ 6, 7, 9, afford a complete solution of the equation of condition. The process may be thus described. It depends upon the solution of equations of two types, A and B say; of which

$$(v, w, x, y, z) = 2(u, v, w, x, y) \qquad \text{(A)}$$

and

$$(v, w, x, y, z) = (v, w, x, y) + (w, x, y, z) + (w, x, y)\,. \qquad \text{(B)}$$

are examples. The equation of condition, to begin with, is of the type A. We show that this can be made dependent upon an equation of the type A but of lower order, and upon an equation of the type B. Next we show that the equation of type B depends on the solution of another of type B of lower order, and on the solution of two equations of type A. Thus by repeated partial solutions the desired result is obtained.

A caution, however, is requsite in regard to the *ultimate* equations of the two types. In the case of type A the ultimate form may be

either $$(x, y, z) = 2(w, x, y) \qquad (\mathrm{A}z)\,,$$

or $$(y, z) = 2(x, y) \qquad (\mathrm{A}_2)\,.$$

The former has for solutions

$$\left.\begin{array}{ll} (1) & z = 2w,\, x = 2y, \\ (2) & z = 2w + 1,\, x = 1,\, y = 2\,; \end{array}\right\}$$

the latter has $$z = 2x + 1,\, y = 1\,.$$

In the case of type B the ultimate form may be either

$$(x, y, z) = (x, y) + (y, z) + y \qquad (\mathrm{B}z)$$

or $$(x, y) = x + y + 1 \qquad (\mathrm{B}_2)$$

The solutions of the former are

$$\left.\begin{array}{ll} (1) & x = 1,\, z = 2y + 1\,, \\ (2) & x = y = z = 2\,, \\ (3) & x = 2y + 1,\, z = 1\,: \end{array}\right\}$$

of the latter $$x = y = 2\,.$$

11. The application of the theorem in § 8 effects a considerable simplification of this process. Whenever an equation of type B is reached, it enables us to dispense with the consideration of the last and most troublesome of the three partial solutions given in § 9. For, this solution is

$$q_3 = 2 + \ ,\ q_{z-2} = 1, \text{ and } (1 + \alpha, q_4\,, \ldots, q_{z-4}) = 2(q_4\,, \ldots, q_{z-3})\,,$$

and (§ 8) we have already virtually got it from the first of the three, viz.,

$$q_3 = 1, \text{ and } (q_5, \ldots, q_{z-3}, q_{z-2} - 1) = 2(q_4, \ldots, q_{z-3}),$$

because in the change which is the test of the symmetry of the equation q_3 and q_{z-2} are interchanged letters. In short, if we consider the case where $q_3 = 1$, we do not require to consider the case where $q_{z-2} = 1$.

12. Taking the case of a cycle of 16 elements,

$$a, b, c, d, e, f, g, h, g, f, e, d, c, b, a,$$

the equation of condition is

$$(b, c, d, e, f, g) = 2(a, b, c, d, e, f).$$

The solution leads to the following "tree":—

- $(b, c, d, e, f, g) = 2(a, b, c, d, e, f)$
  - $g = 2a$, $(b, c, d, e) = 2(c, d, e, f)$
    - $b = 2f$, $(d, e) = 2(c, d)$
      - $e = 2c + 1, d = 1$
    - $b = 2f + 1$, $e = 1$, $(c, d) = c + d + 1$
      - $c = d = 2$
  - $g = 2a + 1$, $b = 1$, $(c, d, e, f) = (c, d, e) + (d, e, f) + (d, e)$
    - $c = 1$, $(e, f - 1) = 2(d, e)$
      - $f = 2d + 2, e = 1$
    - $c = 2$, $f = 2$, $(d, e) = d + e + 1$
      - $d = e = 2$

so that the possible cycles are :—

a,	$2f$,	c,	1,	$2c+1$,	f,	$2a$,	$\{\ \}$, ...
a,	$2f+1$,	2,	2,	1,	f,	$2a$,	$\{\ \}$, ...
a,	1,	1,	d,	1,	$2d+2$,	$2a+1$,	$\{\ \}$, ...
a,	1,	$2d+2$,	1,	d,	1,	$2a+1$,	$\{\ \}$, ...
a,	1,	2,	2,	2,	2,	$2a+1$,	$\{\ \}$, ...

where $\{\ \}$ indicates the middle of the symmetric portion of the cycle. All of them are shown by the tree except the fourth, which is got from third by the theorem of § 8.

The following are the like results for cycles of less than 16 elements :—

Elements in cycle.	Cycle itself (up to middle element).						
2.	$\{\ \}$, ...						
4.	impossible.						
6.	a, $2a$, $\{\ \}$, ...						
8.	a,	1,	$2a+1$,	$\{\ \}$, ...			
10.	a,	1,	2,	$2a+1$,	$\{\ \}$, ...		
	a,	$2b$,	b,	2,	$\{\ \}$, ...		
12.	a,	$2b+1$,	1,	b,	$2a$,	$\{\ \}$, ...	
	a,	1,	2,	2,	$2a+1$,	$\{\ \}$, ...	
14.	a,	$2b$,	c,	$2c$,	b,	$2a+1$,	$\{\ \}$, ...
	a,	$2b+1$,	2,	1,	b,	$2a+1$,	$\{\ \}$, ...
	a,	1,	$2b+1$,	b,	1,	$2a+1$,	$\{\ \}$, ...
	a,	1,	2,	2,	2,	$2a+1$,	$\{\ \}$, ...
	a,	1,	1,	b,	$2b+1$,	$2a+1$,	$\{\ \}$, ...

Numbers whose square roots have these cycles:

2. a^2+2.

4.

6. $\left\{(2a^2+1)\mathrm{M}+a\right\}^2+4a\mathrm{M}+2$.

8. $\left\{(2a^2+4a+1)\mathrm{M}-(a+1)\right\}^2+4(a+1)\mathrm{M}-2$.

10. $\left\{(6a^2+8a+3)\mathrm{M}+(9a+6)\right\}^2+4(3a+2)\mathrm{M}+18$.

$$\left\{(4a^2b^2+4ab+2a^2+1)\mathrm{M}-(2ab^2+a+b)(2b^2+1)\right\}^2$$
$$-4(2ab^2+a+b)\mathrm{M}+2(2b^2+1)^2.$$

&c. &c.

13. The well-known property regarding the quadratic form to which the integers belong whose square roots have culminate cycles, suggests that the coefficient of M in the general expression for these numbers (§ 4) must have the same form. We are thus led to the curious theorem:—

If $(q_2, \ldots, q_{z-1}) = 2(q_1, \ldots, q_{z-2})$ *then* $(q_1, \ldots, q_{z-1})$ *is of the form* $A^2 + 2B^2$ *or* $A^2 - 2B^2$ *according as z is odd or even.*

This further suggests the inquiry as to how A and B are to be obtained in any particular case,—how, for example, knowing that

$$a,\ 2b,\ c,\ 2c,\ b,\ 2a,\ \{\ \},\ \ldots.$$

is a culminate cycle, we can partition $(a, 2b, c, 2c, b, 2a)$ into a square and the double of a square. The result is

$$(a, 2b, c, 2c, b, 2a) = 2(a, 2b, c)^2 + (b, 2a)^2,$$

where the element $2c$ separates the given continuant into two continuants which are B and A. Similarly we have

$$\begin{aligned}
(a, 2b+1, 2, 1, b, 2a) &= 2(a, 2b+1)^2 + (1, b, 2a)^2,\\
(a, 1, 2b+1, b, 1, 2a+1) &= 2(a, 1)^2 + (b, 1, 2a+1)^2,\\
(a, 1, 2, 2, 2, 2a+1) &= 2(a, 1, 2)^2 + (2, 2a+1)^2,\\
(a, 1, 1, b, 2b+1, 2a+1) &= 2(a, 1, 1, b^2) + (2a+1)^2.
\end{aligned}$$

14. Closely associated with culminate cycles are those in which the middle element of the cycle is *less by* 1 than the unique partial quotient; for example,

$$\sqrt{107} = 10 + \frac{1}{\underset{*}{2}+}\frac{1}{1+}\frac{1}{9+}\frac{1}{1+}\frac{1}{2+}\frac{1}{\underset{*}{20}+}\ldots$$

Indeed, the two cases are almost co-extensive with the case where the middle element of the cycle of *divisors* is 2: the exact state of matters being that if the middle element of the cycle of divisors be 2 the cycle of partial quotients is culminate or peneculminate, and if the latter cycle be culminate or peneculminate the middle element of the divisors is 2, except in the solitary instance of $\sqrt{12}$ where it is 3.

The complete theory of peneculminate cycles can be very shortly given after what has preceded.

15. *The necessary and sufficient condition that the middle element*

q_z *of the cycle of partial quotients shall be* 1 *less than the unique partial quotient is*

$$(q_1, \dots q_{z-1}) + (q_2, \dots, q_{z-1}) = 2(q_1, \dots, q_{z-2}) .$$

16. *If* $\sqrt{A^2 + D}$ *be expressed as a continued fraction with unit-numerators, and the middle element* q_z *of the cycle of partial quotients be equal to* $A - 1$, *then*

$$D = \frac{(q_2, \dots, q_{z-1}A) + (q_2, \dots, q_{z-1}, A-1)}{(q_1, \dots, q_{z-1})} .$$

This and the preceding proposition are established exactly as the corresponding propositions regarding culminate cycles have been established (§§ 2, 3).

17. *The condition* $(q_1, \dots, q_{z-1}) + (q_2, \dots, q_{z-1}) = 2(q_1, \dots, q_{z-2})$ *being satisfied, the general expression for all integers whose square roots have peneculminate cycles is*

$$\tfrac{1}{4}\left[(-1)^z(2M-1)(q_1, \dots, q_{z-1}) - (-1)^z 2(q_1, \dots, q_{z-2})(q_2, \dots, q_{z-2}) + 1\right]^2$$
$$+ (-1)^z\{(2M-1)(q_2, \dots, q_{z-1}) - 2(q_2, \dots, q_{z-2})^2\} .$$

From § 16 we have

$$D = \frac{(q_2, \dots, q_{z-1}, A) + (q_2, \dots, q_{z-1}, A-1)}{(q_1, \dots, q_{z-1})}$$
$$= \frac{(2A-1)Q_{z-1} + 2Q_{z-2}}{P_{z-1}} .$$

whence, as in § 4,

$$DP_{z-2} = (2A-1)Q_{z-2} + \frac{(-1)^z(2A-1) + 2P_{z-2}Q_{z-2}}{P_{z-1}} .$$

Now since (§ 15) $P_{z-1} + Q_{z-1} = 2P_{z-2}$, then P_{z-1} and Q_{z-1} are both even or both odd: but they are mutually prime, therefore they are both odd. We thus have the foregoing fractional form = an odd integer $= 2M - 1$ say. This leads, as in § 4, to

$$2A = (-1)^z(2M-1)P_{z-1} - (-1)^z 2P_{z-2}Q_{z-2} + 1$$
$$\text{and} \quad D = (-1)^z(2M-1)Q_{z-1} - (-1)^z 2Q^2_{z-2}$$

whence the desired formula.

18. *In a peneculminate cycle of* $2z$ *elements* q_1, q_2, &c., *we have* $q_{z-1}=1$, *and for the determination of the others*

$$(q_1, \ldots, q_{z-2}) = (q_1, \ldots, q_{z-3}) + (q_2, \ldots, q_{z-2}) + (q_2, \ldots q_{z-3}).$$

From § 15 we have

$$\begin{aligned} 2(q_1, \ldots, q_{z-2}) &= (q_1, \ldots, q_{z-1}) + (q_2, \ldots, q_{z-1}) \\ &= q_{z-1}(q_1, \ldots, q_{z-2}) + (q_1, \ldots, q_{z-3}) \\ &\qquad + q_{z-1}(q_2, \ldots, q_{z-2}) + (q_2, \ldots, q_{z-3}) \end{aligned}$$

$$\begin{aligned} \therefore \quad q_{z-1} &< 2 \\ &= 1 \end{aligned}$$

and $\therefore$

$$(q_1, \ldots, q_{z-2}) = (q_1, \ldots, q_{z-3}) + (q_2, \ldots, q_{z-2}) + (q_2, \ldots, q_{z-3}).$$

19. As the equation here got for the determination of $q_1, q_2, \ldots, q_{z-2}$ is of the type B formerly investigated in connection with culminate cycles, it is evident that having got all possible culminate cycles of $2z$ elements we can at once write down all possible peneculminate cycles of $2z-4$ elements. Thus suppose it be required to find all the peneculminate cycles of 12 elements. Representing the cycle by

$$a, b, c, d, e, \{\ \}, \ldots .$$

we know that $e=1$ and that for the determination of a, b, c, d we have

$$(a, b, c, d) = (a, b, c) + (b, c, d) + (b, c).$$

The solutions of this equation, however, have been found in § 12, in considering the culminate cycles of 16 elements, to be

$$\begin{aligned} a, b, c, d &= 1 \quad , b , 1 , 2b+2 \\ &= 2b+2 , 1 , b , 1 \\ &= 2 \quad , 2 , 2 , 2 . \end{aligned}$$

Thus all the peneculminate cycles of 12 elements are

$$\begin{array}{llllll} 1 & , b , & 1 , & 2b+2 , & 1 , & \{\ \}, \ldots \\ 2b+2 , & 1 , & b , & 1 & , 1 , & \{\ \}, \ldots \\ 2 & , 2 , & 2 , & 2 & , 1 , & \{\ \}, \ldots \end{array}$$

The connection between the two kinds of cycles may be best formulated thus:—*Every culminate cycle of the form*

$$a , 1 , \pi , \rho , \sigma , \ldots , \omega , 2a+1 , \{\ \} , \ldots .$$

has corresponding to it a peneculminate cycle of the form

$$\omega\ , \ldots , \sigma\ , \rho\ , \pi\ , \{\ \}\ , \ldots .$$

and there are no other peneculminate cycles.

The equation of condition $P_{z-1}+Q_{z-1}=2P_{z-2}$ is inapplicable when $z=2$ or 1: in the former case we have

$$\sqrt{A^2+2A-1}=A+\frac{1}{\overset{}{\underset{*}{1}}+}\,\frac{1}{A-1+}\,\frac{1}{1+}\,\frac{1}{\underset{*}{2A}}+\ldots$$

in the latter, the solitary example

$$\sqrt{12}=3+\frac{1}{\underset{*}{2}+}\,\frac{1}{\underset{*}{6}+}\,\ldots$$

20. The same considerations which led to the theorem of § 13 give us now the theorem :—

If $(q_1\ , \ldots , q_{z-1})+(q_2\ , \ldots , q_{z-1})=2(q_1\ , \ldots , q_{z-2})$ *then* $(q_1\ , \ldots , q_{z-1})$ *is of the form* A^2+2B^2 *or* A^2-2B^2, *according as* z *is odd or even.*

Also, the expressions for A and B present themselves in the same simple manner as before: thus for the cycles above obtained we have

$$\begin{aligned}(1\ , b\ , 1\ , 2b+2\ , 1)&=-2(1\ , b)^2+(2b+2\ , 1)^2\ ;\\ (2b+2\ , 1\ , b\ , 1\ , 1)&=-2\cdot 1^2\ \ +(1\ , b\ , 1\ , 1)^2\ ;\\ (2\ , \quad 2\ , 2\ , 2\ , 1)&=-2\cdot 2^2\ \ +(2\ , 2\ , 1)^2.\end{aligned}$$

21. It only remains now to see if we can ascertain how many different kinds of culminate and peneculminate cycles there ought to be with a given number of elements. If the number of elements be $2z$, then in the case of culminate cycles what we have to find is the number of solutions of an equation of type A (§ 10) and of the $(z-2)$th degree. Let the said number be denoted by α_{z-2} and let β be used in a similar way in connection with equations of type B. Then (§ 10) we have the pair of difference-equations

$$\left.\begin{aligned}\alpha_{z-2}&=\alpha_{z-4}+\beta_{z-4}\\ \beta_{z-2}&=2\alpha_{z-4}+\beta_{z-4}\end{aligned}\right\}$$

and also (§ 10) the initial conditions

$$\alpha_2 = 1 \, , \, \beta_2 = 1$$
$$\alpha_3 = 2 \, , \, \beta_3 = 3 \, .$$

From the two equations by division we have

$$\frac{\beta_{z-2}}{\alpha_{z-2}} = 1 + \frac{\alpha_{z-4}}{\alpha_{z-4} + \beta_{z-4}}$$
$$= 1 + \cfrac{1}{1 + \cfrac{\beta_{z-4}}{\alpha_{z-4}}}$$

Therefore when z is even

$$\alpha_{z-2} = (2 \, , \, 2 \, , \, 2 \, , \ldots)_{\frac{1}{2}z-2}$$
$$\beta_{z-2} = (1 \, , \, 2 \, , \, 2 \, , \, 2 \, , \ldots)_{\frac{1}{2}z-1}$$

where the suffix after the bracket of the continuant is used to indicate the number of elements in the continuant; and

when z is odd

$$\alpha_{z-2} = (2 \, , \, 2 \, , \, 2 \, , \, \ldots \ldots)_{\frac{1}{2}(z-3)}$$
$$\beta_{z-2} = (1 \, , \, 2 \, , \, 2 \, , \, 2 \, , \, \ldots)_{\frac{1}{2}(z-1)}$$

Putting $z = 2r$ and then $z = 2r + 1$ we see that

$$\alpha_{2r} = \alpha_{2r+1} \text{ and } \beta_{2r} = \beta_{2r+1}$$

and that there is thus no need of stating the two cases separately. Our result may therefore be put thus: *The number of different kinds of culminate cycles having* 2z *elements is*

$$(2 \, , \, 2 \, , \, 2 \, , \ldots \ldots)_y$$

or $$2^y + (y-1)2^{y-2} + \frac{(y-2)(y-3)}{1 \, . \, 2} 2^{y-4} + \ldots \ldots$$

and the number of different kinds of peneculminate cycles of the same extent is

$$(2 \, , \, 2 \, , \, 2 \, , \ldots \ldots)_y + (2 \, , \, 2 \, , \ldots)_{y-1}$$

where y *is the highest integer in* $\frac{1}{2}(z-3)$.

PRIVATE BUSINESS.

Mr G. A. Woods, Dr Richard Davy, and Dr John Grieve were balloted for, and declared duly elected Fellows of the Society.

PROCEEDINGS

OF THE

ROYAL SOCIETY OF EDINBURGH.

VOL. XII. 1883-84. No. 117.

Monday, 17th March 1884.

ROBERT GRAY, Esq., Vice-President, in the Chair.

The following Communications were read :—

1. The Old Red Sandstone Volcanic Rocks of Shetland. By Messrs B. N. Peach and John Horne, of the Geological Survey of Scotland.

2. On the Principles of Economics. Part I., Mathematical. Part II., Physical. By Mr P. Geddes.

3. An Integrating Hygrometer. By Prof. C. Michie Smith.

This instrument consists essentially of a cryophorus, one bulb of which is kept wet by the same arrangement as is used for a wet-bulb thermometer, while the other bulb is left dry. For convenience, the wet bulb is made spherical, and the dry bulb is made cylindrical, and is graduated. The difference of temperature between the two bulbs produced by evaporation causes a transference of water from the dry bulb to the wet bulb, and the amount of water thus transferred in any period of time, taken along with the mean temperature, will give a measure of the average hygrometric

condition during that time. Preliminary observations with this instrument show that even in comparatively moist weather the total evaporation during twenty-four hours is great enough to be easily measured.

The instrument is intended primarily to be used for determining the total evaporation from tanks and other free surfaces of water. For this purpose it will be used first in connection with an atmometer, devised by Mr G. K. Winter and myself, by means of which we hope to determine with greater accuracy than has yet been done the total evaporation from the surface of a tank. By this means the constant of the hygrometer will be obtained, and future determinations can be made with the hygrometer alone.

Other uses of the instrument will at once suggest themselves, but it is not necessary to go into details till more complete observations have been made.

Monday, 7th April 1884.

ROBERT GRAY, Esq., Vice-President, in the Chair.

The following Communications were read:—

1. On the Philosophy of Language. By Emeritus Professor Blackie.

2. On the Principles of Economics. Part III., Biological and Psychological. By Mr P. Geddes.

3. Note on a New Form of Galvanometer. By Professor James Blyth.

This instrument consists of a close spiral of insulated copper wire bent into the form of an anchor ring, so as to form an endless solenoid. The spiral is placed in a rectangular groove turned on the

edge of a wooden or brass ring of suitable thickness and diameter. Short lengths of wire at both ends of the copper spiral are left straight. These, after being well insulated, are twisted together and led to two terminals, which serve as electrodes. The ring containing the spiral is fixed on a base board with its plane vertical, and at right angles to the magnetic meridian, when the instrument is in use. A short magnet, rigidly attached at right angles to the lower end of a stiff wire, is suspended from a silk fibre, so that its centre is in the circular centre line of the anchor ring. Near the upper end of the wire a long glass fibre pointer is attached, which moves over a horizontal disc graduated to degrees, and the whole is so enclosed so that the magnet, fibre, and pointer are free from currents of air. Fig. 1 gives a sketch of the arrangement, showing, however, the convolutions of the wire much too far apart. These are in reality quite close together on the inner side, the spiral being tied tight into the rectangular groove by means of a cord.

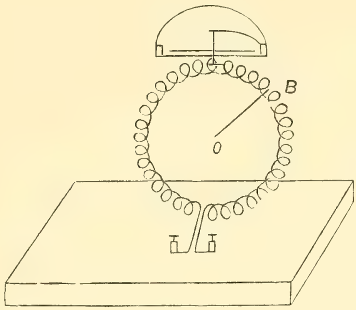


Fig. 1.

Let n = the number of convolutions in the spiral,
r = radius of circular axis of coil = OB,
C = current strength;

then, if θ be the deflection, and H = horizontal intensity of the earth's magnetism, we have

$$\frac{2nC}{r}\cos\theta = H\sin\theta,$$

$$\therefore\ C = \frac{Hr}{2n}\tan\theta.$$

From this formula it will be seen that the galvanometer constant can be very easily determined, since it depends only upon r and n.

Since the endless coil, when carrying a current, forms a closed

magnetic shell, it can exert no magnetic force outside the shell; and hence the current will have no effect upon any system of permanent magnets that may be employed to produce a stronger magnetic field surrounding the needle.

PRIVATE BUSINESS.

Mr James Tait Black and Mr E. Peirson Ramsay were balloted for, and declared duly elected Fellows of the Society.

Monday, 21st April 1884.

Sir WILLIAM THOMSON, Hon. Vice-President, in the Chair.

The following papers were read by Honorary Fellows now in Edinburgh:—

1. On Galvanic Currents passing through a very Thin Stratum of an Electrolyte. By Professor H. von Helmholtz.

If one closes a galvanic circuit containing a small battery, the electromotive force of which is not able to decompose water, and a voltameter with two platinum plates dipping into water acidulated with sulphuric acid, the current has a great intensity in the first moment, and diminishes at first very rapidly, afterwards slowly. At last its intensity approaches to zero more and more, but it never ceases completely. The more sensitive the galvanometer by which you measure its intensity, the longer the time during which you are able to observe the deflection of the needle. If the electrolytic fluid is in contact with atmospheric air, it is easy, even with a galvanometer of simple construction and moderate sensibility, to observe that at last a feeble residue of current remains, keeping a nearly constant intensity. This intensity, however, is increased by the slightest motion of the fluid, also by feeble motions produced by changes of temperature. Under these conditions, it is nearly impossible to determine by measurement regular relations between the electromotive force,

the resistance, and the intensity of the current. Three years ago I had the honour to describe before the Royal Society a little apparatus, hermetically sealed and purified as much as I was able to do from all traces of oxygen and hydrogen. There I thought that the current could be really reduced to zero. But since that time I have applied an extremely delicate galvanometer, and I have found that this cell also lets pass a never-ceasing current even with small electromotive forces. The residual current remaining under such conditions is indeed only the ten thousandth or hundred thousandth part of the current which would be produced by the same electromotive force in a metallic conductor of the same galvanic resistance, and it goes on decreasing through weeks and weeks before it becomes constant, or rather oscillating about a constant mean value.

Lately I have tried to shorten the time through which one has to wait for such observations, and to increase the intensity of the residual current by making the stratum of electrolytic fluid between two plane surfaces of platinum very thin. I have used plane plates of glass lying horizontally and separated by very thin little pieces of clean glass. The two plane plates were platinised along their interior surfaces, and the platinum covering of the superior plate (a rectangle of about 10 and 5 cm. side), which was smaller than the inferior, extended over a part of its upper side in order to fix on the upper sides of both plates two little hollow cylinders of paper containing mercury in contact with the platinum. By the mercury the platinum could be connected with the other parts of the circuit.

If one brings drops of the electrolytic fluid near to the margin of the upper plate, they are sucked in by capillary force into the fissure between the plates and kept fast there. The galvanic resistance of the little apparatus is only a small fraction of an ohm, and can be neglected when compared with the other parts of the circuit, which contained about 600 ohms. The fluid at the edge of the upper plate was in contact with atmospheric air, and therefore saturated with atmospheric oxygen according to its density in the atmosphere.

I was able, indeed, with this little apparatus, to get the constant value of the residual current after six or twelve hours, and to

have it unusually strong. If one compares the intensity of the residual current with that which would have been produced in a metallic conductor of the same resistance (600 ohms), it was about 0·025 of the latter with an electromotive force of 0·8 Daniell, 0·125 with 1·0 Daniell, 0·4 with 2·0 Daniells. I shall not try to give you more exact numbers, because I hope to get them still more accurate than they are at present. But there was not the slightest trace of evolution of gas. And you see that even with two Daniells the current which was kept up required the force of 0·8 Daniells to overcome the resistance of the circuit. Therefore, only 1·2 Daniells remained for the decomposition of the water, which are insufficient to develop the two gases under atmospheric pressure. By reducing the resistance of the circuit to 300 ohms I could get a decomposing force of 1·36 Daniells. But also this was not sufficient for visible decomposition. The arrangement of the apparatus used hitherto did not admit of going farther. For these experiments a very constant electromotive force is needed, which is steady through months, and of which well-measured parts can be derived to pass through the electrolyte, and I had not yet had the time to introduce those modifications of the apparatus which are necessary for the employment of higher electromotive force.

These experiments show that in this case a current of about 0·002 ampère could pass contantly through acidulated water without developing any visible trace of oxygen and hydrogen.

I don't think, nevertheless, that the electrolytic law of *Faraday* is violated in this case. I suppose that really oxygen and hydrogen exist separately at the electrodes, only they don't bubble off, but remain dissolved in the fluid, where they exist electrically neutralised, being no longer subject to electric attraction, and therefore free to migrate through the fluid by diffusion. But when electrically neutral oxygen reaches the cathode, where positive electricity is subject to the attraction of the negative electricity of the metal, it will yield its $+E$ far easier to the cathode than does hydrogen. And the same will happen at the anode. Neutral hydrogen, carried over by diffusion, will yield its $-E$ easier to the positive metal than the anion oxygen will do. This, as you see, produces only a convective current of electricity. At the cathode diffused

oxygen, having given off its $+E$ and now charged with $-E$, will combine with the kation $+H$. At the anode diffused hydrogen, after having received a positive charge from the metal, will combine with the anion $-O$. So the results of the electrolytic decomposition of water are annihilated continually. Oxygen, charged negatively, migrates as anion from the cathode to the anode, then, neutralised, it is carried back to the cathode. Hydrogen, charged and discharged, goes in the opposite direction. The work done by the electromotive force of the battery is not chemical decomposition, but it is this migration of the constituents of the fluids by which heat ought to be evolved. That heat, which is evolved by the migration of the ions, falls under the heat evolved by galvanic resistance, but the heat evolved by diffusion ought to be proportional to the intensity of the current. But before this stationary state of the current can be produced, electrolytic decomposition must go on till the required amount of gases is dissolved in the fluid, if there is not already from the beginning a sufficient quantity of one of the gases, viz., oxygen, of the atmosphere in solution. Here the thermodynamic inferences come into play, which I have developed lately from the law of *Carnot*. They show that a limited quantity of the gases can be produced electrolytically even by very feeble electromotive forces, till a certain value of density of the dissolved gases corresponding to the value of the decomposing force has been reached.

Out of these thermodynamic laws one can develop a complete mathematical theory of galvanic polarisation and its effects. As far as the accuracy of my measurements reaches, the facts appear to be in sufficient harmony with such a theory.

2. On Cosmic Dust. By l'Abbé Renard.

3. Esempio del metodo di dedurre una superficie da una figura piana. By Professor Cremona.

Scopo della presente piccolo comunicazione di mostrare con un asempio notevole, ed in connessione colla teoria conosciuta delle

rappresentazione piana di una certa classe di superficie, e con quella delle trasformazioni razionali nello spazio, come da un sistema piano di punti, rette e curve si possono dedurre la costruzione e le proprietà di superficie situate comunque nello spazio (di quelle che sono rappresentabili punto per punto sul piano).

Se sono dati sei punti 123456 in un piano, per essi passano quindici rette e sei coniche. Ciascuno de' sei punti è doppio per infinite cubiche (curve di 3° ordine) passanti per gli altri cinque, formanti un fascio; le tangenti nel punto doppio sono percio in involuzione. I sei punti doppi danno così sei involuzioni. Allora si puo domandare di costruire una curva K_6 di 6° ordine, che abbia sei punti doppi in 123456 e per tangenti altrettante coppie delle sei involuzioni. Il problema è risoluto dalle Iacobiane delle reti di cubiche passanti per i sei punti dati. Le K_6 costituiscono un sistema lineare tre volte infinito, ossia sono combinazioni lineari di quattro K_6 fra loro indipendenti. Vi sono altre involuzioni, in ciascuna delle quindici rette e delle sei coniche. L' involuzione in una retta 12 è determinata dal fascio delle coniche 3456; e l' involuzione in una conica 12345 dal fascio delle rette per 6. Le curve K_6 segano ciascuna delle quindici rette—delle sei coniche sempre in coppie di punti dell' involuzione. Vi sono poi infiniti punti dotati della proprietà che tutte le curve K_6 passanti per uno di essi ivi si toccano; il loro luogo è una curva H_{12} del dodicesimo ordine, aventi sei punti quadrupli in 123456, e tangenti alle quindici rette ed alle sei coniche nei punti doppi delle involuzioni, e nei punti quadrupli ai raggi doppi delle involuzioni rispettive.

Possiamo ora prendere le K_6 come imagini delle sezioni piane d'una superficie. L' ordine sarà $6 \cdot 6 - 6 \cdot 4 = 12$. Essa ha ventisette rette doppie, le cui imagini sono i sei punti dati, le quindici rette e le sei coniche. Ha inoltre quarantacinque punti tripli né quali le ventisette rette nodali concorrono tre a tre.

La superficie ha poi una curva cuspidale avente per imagine H_{12}; e siccome questa è incontrata da ogni K_6 in $6 \cdot 12 - 6 \cdot 2 \cdot 4 = 24$ punti, così la curva cuspidale è del 24° ordine.

Di qual classe è la superficie? Ai piani tangenti che passano per un punto O dello spazio corrispondono K_6 formanti una rete, la cui

Iacobiana sarà l' imagine della curva di contatto della superficie col cono circoscritto. La Iacobiana d' una rete di K_6 è dell' ordine $3 \cdot 5$ e passa con $3 \cdot 2 - 1 = 5$ rami per ciascuno de' punti dati. Ma di essa è evidentemente parte la H_{12}; dunque la curva residua è una cubica coi punti semplici 123456; e siccome due curve analoghe si segano in altri tre punti, così la superficie è della terza classe.

Si vede così che la superficie è la reciproca della superficie generale di terzo ordine.

Monday, 5th May 1884.

ROBERT GRAY, Esq., Vice-President, in the Chair.

The following Communications were read:—

1. On the Construction of the Canon of Logarithmic Sines. By Edward Sang, LL.D.

In setting about the construction of the Canon of Logarithmic Sines, we naturally look for any means of lessening the heavy labour of the undertaking.

The very first table of logarithms, that given by Nepair in his *Canon Mirificus*, was one of logarithmic sines, and was made by the actual computation of the logarithms as given in Reinhold's table of sines (see Constructio, section 39). But, in the modern text-books on trigonometry, we are told that the logarithms may be computed independently of the sines themselves. If this computation be less laborious than, and as trustworthy as, the operation from the already computed sines, it must be adopted. Our canons of sines, and of logarithms to fifteen places, then only serve for occasional verifications.

In the introduction to Callet's admirable collection of Tables Portatives, the investigation of the formulæ and the series for the logarithmic sines are given. According to the rule strictly followed in the preceding works, each of our steps must be made independ-

ently of all previous computations, and thus we come to revise critically the deduction of the formulæ themselves, and of the series resulting from them.

It is pointed out that if, in the series for the cosine of an arc, viz. :—

$$\cos a = 1 - \frac{a^2}{1.2} + \frac{a^4}{1.2.3.4} - \frac{a^6}{1\,.\,.\,.\,.\,.\,6} + \&c.$$

we substitute for a, the length q, of a quadrant, the cosine becomes zero; and that, according to the law for equations, the series is divisible by $1 - \frac{a}{q}$. But the cosine is also zero for $a = -q$, hence the series being divisible also by $1 + \frac{a}{q}$, is divisible by the product $1 - \frac{a^2}{q^2}$. In the same way, since the cosine is zero at each odd quadrant, the terms $1 - \frac{a^2}{3^2q^2}$, $1 - \frac{a^2}{5^2q^2}$, $1 - \frac{a^2}{7^2q^2}$, and so on, are all divisors of the series; whence it is concluded that the cosine is the continued product of all these divisors to infinity, or that

$$\cos a = \left(1 - \frac{a^2}{q^2}\right)\left(1 - \frac{a^2}{3^2q^2}\right)\left(1 - \frac{a^2}{5^2q^2}\right)\left(1 - \frac{a^2}{7^2q^2}\right)\ldots\ldots\ldots$$

By similar arguments it is shown that

$$\sin a = a\left(1 - \frac{a^2}{2^2q^2}\right)\left(1 - \frac{a^2}{4^2q^2}\right)\left(1 - \frac{a^2}{6^2q^2}\right)\ldots\ldots\ldots$$

Taking now the logarithm of each side of the equation, and using the formula

$$\log\,(1 - x) = -\frac{x}{1} - \frac{x^2}{2} - \frac{x^3}{3} - \frac{x^4}{4} - \&c.;$$

collecting also the terms containing the like powers of a, we get

$$\log \sec a = \frac{a^2}{q^2}\cdot\left\{\frac{1}{1^2} + \frac{1}{3^2} + \frac{1}{5^2} + \frac{1}{7^2} + \&c.\right\}$$

$$+ \frac{a^4}{q^4}\cdot\tfrac{1}{2}\left\{\frac{1}{1^4} + \frac{1}{3^4} + \frac{1}{5^4} + \frac{1}{7^4} + \&c.\right\}$$

$$+\frac{a^6}{q^6}\cdot\tfrac{1}{3}\left\{\frac{1}{1^6}+\frac{1}{3^6}+\frac{1}{5^6}+\frac{1}{7^6}+\&c.\right\}$$

and so on.

$$\log\frac{a}{\sin a}=\frac{1}{q^2}\cdot\left\{\frac{1}{2^2}+\frac{1}{4^2}+\frac{1}{6^2}+\frac{1}{8^2}+\&c.\right\}$$

$$+\frac{a^2}{q^4}\cdot\tfrac{1}{2}\left\{\frac{1}{2^4}+\frac{1}{4^4}+\frac{1}{6^4}+\frac{1}{8^4}+\&c.\right\}$$

$$+\frac{a^6}{q^6}\cdot\tfrac{1}{3}\left\{\frac{1}{2^6}+\frac{1}{4^6}+\frac{1}{6^6}+\frac{1}{8^6}+\&c.\right\}$$

and so on.

There remains for us the summation of these series of inverse powers. M. Callet says—"Sommant enfin toutes ces séries, nous aurons, en nous bornant à vingt décimales" (lastly, summing all these series, confining ourselves to twenty places, we shall have), &c., leaving us to understand that the results are obtained by actual summation. Let us proceed to verify the first coefficient by this method:—we have

$1^{-2}=$	1.00000 00000 00000 00000
$3^{-2}=$	11111 11111 11111 11111
$5^{-2}=$	4000 00000 00000 00000
$7^{-2}=$	2040 81632 65306 12245
$9^{-2}=$	1234 56790 12345 67901
$11^{-2}=$	826 44628 09917 35537
. .	. . . .
$101^{-2}=$	9 80296 04940 69289
. .	. . . .
$1001^{-2}=$	9980 02996 00499
$1003^{-2}=$	9940 26892 40355

Here the progression is so slow that, after five hundred divisions, which bring us to the divisor 1001, we have got only to the sixth place. The convergence is becoming rapidly less, and we should need to use five thousand million of terms ere our quotient be brought below the twentieth decimal place. Worse than that:—the succeeding terms diminish so very slowly that their sum may

reach to a thousand million of units in the twentieth place; that is to say, with five thousand million of terms we shall not be sure of the result in the tenth place.

Thus it is clear that M. Callet did not get his numbers by the summation of the series; he must have got them elseways. These series, though interesting and valuable, are useless in calculation; they are not even established by the arguments adduced. The logic is as faulty as the logistics.

When a polynome consists of a finite number of terms, each a multiple of an integer positive power of some variable x, and when the substitution of a definite value r for x renders that polynome zero, it is easy to show that the expression is divisible by the difference $x - r$, the quotient being another polynome one degree lower in rank.

The proof of this theorem rests essentially on the finitude of the expression; the very idea of divisibility implies a termination. Hence in extending this law to interminate progressions we destroy the foundation on which the argument rests. Granted the use of unending series, we may divide any finite polynome by any binome, the quotient being an endless progression; there is now no indivisibility, and the adjective *divisible* ceases to have a meaning. It is absurd to say that the progression

$$1 - \frac{x^2}{2} + \frac{x^4}{1 \ldots 4} - \frac{x^6}{1 \ldots 6} + \text{\&c.}$$

is divisible by $1 - \frac{x^2}{q^2}$; the result of the division by any binome of the form $1 - \alpha x^2$ will be a progression arranged according to the ascending even powers of x. If we divide the quotient by another binome $1 - \beta x^2$, the new quotient again by $1 - \gamma x^2$, and so on, we shall find no obstacle to the divisibility except the labour of the operation. Shall we thence argue that the original series is the continued product of $(1 - \alpha x^2)(1 - \beta x^2)(1 - \gamma x^2)$? Truly not, for that would be to omit from consideration the essential item, the quotient resulting from the divisions. It is necessary to show that the successive divisions of the series for the cosine by $1 - \frac{x^2}{q^2}$,

$1-\dfrac{x^2}{9q^2}$, $1-\dfrac{x^2}{25q^2}$, will result, if carried on to infinity, in the ultimate quotient *unit.*

The fallacy of these arguments may be clearly seen from another point of view. A certain curve crosses the line of abscissæ at equal intervals extending indefinitely both ways. If we place the origin of the abscissæ at the middle of one of the intervals, and denote the ordinate y by the general symbol ϕx, y becomes zero on substituting for x any odd multiple of the half interval; which half interval we shall denote by q; that is to say, $\phi(\pm q)$, $\phi(\pm 3q)$, $\phi(\pm 5q)$, &c., are all zero. Hence, according to these arguments, the expression for y or ϕx must be the continued product of the factors

$$1-\frac{x^2}{q^2},\quad 1-\frac{x^2}{9q^2},\quad 1-\frac{x^2}{25q^2},\ \text{to infinity,}$$

and thus our curve can be none other than the curve of sines; or, to state the conclusion in all its absurdity, no curve other than the curve of sines can cross its axis at equal intervals extended indefinitely both ways!

In the continued product of any number of factors of the form $1-\alpha x^2$, $1-\beta x^2$, $1-\gamma x^2$ . . . . , the coefficient of x^2 is the sum of all the coefficients α, β, γ . . . . ; that of x^2 is the sum of the products of each pair of them; and so on, or, in the usual notation,

$$(1-\alpha x^2)(1-\beta x^2)(1-\gamma x^2)\ldots = 1 - x^2\Sigma\alpha + x^4\Sigma\alpha\beta - x^6\Sigma\alpha\beta\gamma\ldots,$$

and thus, in accepting the above arguments, we assume, inadvertently, that the interminate series

$$\frac{1}{q^2}+\frac{1}{9q^2}+\frac{1}{25q^2}+\ldots.$$

amounts exactly to $\frac{1}{2}$; that is to say, we assume the equality

$$\tfrac{1}{2}=\frac{1}{q^2}\left\{\frac{1}{1^2}+\frac{1}{3^2}+\frac{1}{5^2}+\ \&c.\right\},$$

or

$$\frac{q^2}{2}=\frac{\pi^2}{8}=\frac{1}{1^2}+\frac{1}{3^2}+\frac{1}{5^2}+\frac{1}{7^2}+\ \&c.,$$

and have accomplished the very difficult problem of summing the

inverse powers of the odd numbers, without having been conscious of the fatigue of the operation. Nay, even in our advanced text books on trigonometry, this gratuitous assumption is used to demonstrate its own truth.

Our "taking for granted" does not cease here; we have to consider the subsequent terms of the progression. The sum of the products, two and two, of all the quantities

$$\frac{1}{q^2}, \frac{1}{3^2q^2}, \frac{1}{5^2q^2}, \frac{1}{7^2q^2}, \dots$$

must amount exactly to $\frac{1}{24}$. Now it is well known that the square of the sum of any quantities exceeds the sum of their squares by twice their product, taken two and two, or that

$$(\Sigma\alpha)^2 = \Sigma . \alpha^2 + 2\Sigma . \alpha\beta,$$

but we have already assumed $\Sigma\alpha$ to be $\frac{1}{2}$, we now assume $\Sigma . \alpha\beta$ to be $\frac{1}{24}$, and the obvious result of the two assumptions is that $\Sigma . \alpha^2 = \frac{1}{6}$. Thus, by this easy process, we find that

$$\frac{1}{6} = \frac{1}{1^4q^4} + \frac{1}{3^4q^4} + \frac{1}{5^4q^4} + \frac{1}{7^4q^4} + \&c.$$

or that

$$\frac{q^4}{6} = \frac{\pi^4}{96} = \frac{1}{1^4} + \frac{1}{3^4} + \frac{1}{5^4} + \frac{1}{7^4} + \&c.$$

The same line of exposition may be continued indefinitely, and it now becomes clear that M. Callet has not got the numerical values of his coefficients from the impracticable summations of the series (de toutes ces séries); but that he has deduced the sums by a totally different and manageable process.

The following process for computating directly the sum of the inverse second powers of the natural numbers may, perhaps, have some points of novelty and interest.

Denoting by the symbol ϕx, a function whose development is

$$\phi x = \frac{x}{1^2} + \frac{x^2}{2^2} + \frac{x^3}{3^2} + \frac{x^4}{4^2} + \frac{x^5}{5^2} + \&c.,$$

we observe that this series is convergent for every value of x less than unit, and even so for unit itself; but that for any value of x greater than unit by however little, its terms ultimately increase so that their sum either is infinite, or represents an unreality. It is thus a moot question whether just at the limit $x=1$, ϕx be or be not infinite.

On taking the differentials we get

$$\frac{\delta . \phi x}{\delta x} = \frac{1}{1} + \frac{x}{2} + \frac{x^2}{3} + \frac{x^3}{4} + \frac{x^4}{5} + \&c.$$

$$= \frac{-\log(1-x)}{x}$$

and thus we have

$$\phi x = \int \frac{-\log(1-x)}{x} \delta x \text{ and } \phi 1 = \int_0^1 \frac{-\log(1-x)}{x},$$

so that we shall have the required sum, if we can put this integral in a concrete form.

Having constructed a logarithmic curve with AB for its base and AO for the length of its subtangent, take in it some point C and draw CE parallel to BA, then EC is the logarithm of AE. Hence if we place the origin of co-ordinates at O and denote OA by unit, OE by x, we have $CE = -\log(1-x)$.

If now we continue a straight line OC to meet AB in D, and draw DF parallel to AO to meet the continuation of EC, EF = AD becomes $\dfrac{-\log(1-x)}{x}$. If C be carried along the logarithmic curve, the corresponding point F will trace the curve shown in the figure. When C comes to O, the secant OC merges into the tangent, equally inclined to the abscissæ and ordinates; hence the distance OG must be equal to OA. When C passes to the other side of O, the curve continues above G still nearing the interminate line AOM without ever reaching to it. The curve has thus two asymptotes AB and AM.

The surface EOGF thus represents the integral

$$\int \frac{-\log(1-x)}{x} \delta x \text{ or } \frac{x}{1^2} + \frac{x^2}{2^2} + \frac{x^3}{3^2} + \&c.,$$

and the entire surface AOGF..... B is the value of the series $\frac{1}{1^2}+\frac{1}{2^2}+\frac{1}{3^2}+$ &c., as measured in squares of the unit OA.

If, in the expression

$$\delta\,.\,\phi x = -\log(1-x)\,.\,\frac{\delta x}{x}$$

we substitute $1-x$ for x, we have

$$\delta\,.\,\phi(1-x) = -\log x\,.\,\frac{\delta(1-x)}{1-x},$$

whence

$$\delta\left\{\phi x + \phi(1-x\right\} = -\log(1-x)\,.\,\delta\log x - \log x\,.\,\delta\log(1-x)\,;$$

which, on be integrated, becomes

$$\phi x + \phi(1-x) = \mathrm{C} - \log x\,.\,\log(1-x)\,.$$

Having made O*e* equal to AE or $1-x$, draw *ecf* parallel to ECF; then is the surface *e*OG*f* the representative of $\phi(1-x)$, and

$$\mathrm{EOGF} + e\mathrm{OG}f + \mathrm{EC}\,.\,ec = \mathrm{C}\,.$$

Again, if through K, the middle of OA, we draw KNL parallel to AB, the equation takes the form

$$2\,.\,\mathrm{KOGL} + \mathrm{KN}^2 = \mathrm{C}\,,$$

so that the nnmerical value of the constant of integration is easily computed; it is represented by the algebraic symbol

$$\mathrm{C} = (\log 2)^2 + 2\left\{\frac{1}{2^1\,.\,1^2} + \frac{1}{2^2\,.\,2^2} + \frac{1}{2^3\,.\,2^2} + \frac{1}{2^4\,.\,5^2} + \&c.\right\}.$$

Each term of this progression is less than half of the preceding term, so that the convergence is not slow. When the computation is carried to a considerable number of places, the convergence is so nearly by halving, that the sum of the terms beyond the last computed one may be held as nearly a repetition thereof.

The following is the computation to ten places :—

Computation of $\phi\frac{1}{2}$.

1	.50000			.50000	00000	00
2	.25000			6250	00000	00
3	.12500			1388	88888	89
4	. 6250			390	62500	00
5	3125			125	00000	00
6	1562	50000		43	40277	78
7	781	25000		15	94387	75
8	390	62500		6	10351	56
9	195	31250		2	41126	54
10	97	65625			97656	25
11	48	82812	50		40353	82
12	24	41406	25		16954	21
13	12	20703	12		7223	09
14	6	10350	56		3114	04
15	3	05175	78		1356	34
16	1	52587	89		596	04
17		76293	95		263	99
18		38146	97		117	74
19		19073	49		52	83
20		9536	74		23	84
21		4768	37		10	81
22		2384	18		4	93
23		1192	09		2	25
24		596	05		1	03
25		298	02			48
26		149	01			22
27		74	50			10
				Succeeding terms		9
		$\phi\frac{1}{2}=$		.58224	05264	62

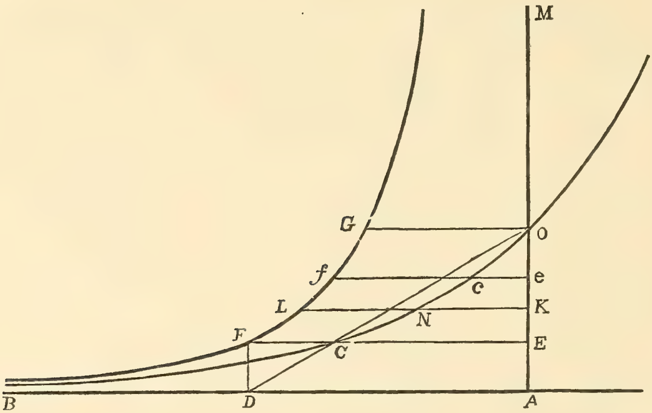
Hence the value of the constant C is

$$\begin{array}{rl} 2.\phi\frac{1}{2} & = 1.16448 \quad 10529 \quad 2 \\ (\log 2)^2 & = .48045 \quad 30139 \quad 2 \\ \hline C & = 1.64493 \quad 40668 \quad 4 \end{array}$$

On giving to x a value very little less than unit, the point E

comes close up to A, and at the same time, e to O. Hence for $x=1$, the area $eOGf$ becomes zero, and thus the ultimate area AOG ... B, has for its value the constant C less the limiting value of the rectangle under the two logarithms ec and EC.

Now on halving the minute distance eO, we render ec rather less



than half; but instead of doubling the line EC, when close to AB, we only augment its length by KN, the logarithm of 2. And thus the rectangle EC . ec is almost exactly halved; the halving being more and more nearly exact the more minute AE is made; hence the limiting value of EC . ec is zero, and the constant C is nothing else than the representation of the area AOG ... B, or of the sum of the series of inverse squares; that is

$$C = 1{\cdot}64493\ 40668 = \frac{1}{1^2} + \frac{1}{2^2} + \frac{1}{3^2} + \frac{1}{4^2} + \frac{1}{5^2} + \ \&c.$$

Now the square of the number π is 9.86960 44011, the sixth part of which is exactly C, so that

$$\frac{\pi^2}{6} = \frac{1}{1^2} + \frac{1}{2^2} + \frac{1}{3^2} + \frac{1}{4^2} + \frac{1}{5^2} + \frac{1}{6^2} + \ \&c.$$

This process, although it bring out the agreement of the value of the sum of the series with that of the sixth part of the square of π, is unsatisfactory, because it gives us a mere arithmetical coincidence, without showing why that coincidence should be.

Taking the fourth part of the above

$$\frac{\pi^2}{24} = \frac{1}{2^2} + \frac{1}{4^2} + \frac{1}{6^2} + \frac{1}{8^2} + \&c.$$

and subtracting, we get for the inverse squares of the old numbers

$$\frac{\pi^2}{8} = \frac{1}{1^2} + \frac{1}{3^2} + \frac{1}{5^2} + \frac{1}{7^2} + \&c.$$

thus showing that the term $\frac{x^2}{1 . 2}$ of the series $1 - \frac{x^2}{1 . 2} + \frac{x^4}{1 . - 4} - \frac{x^6}{1 - 6} + \&c.$, would be exhausted by the divisors $1 - \frac{x^2}{1^2 q^2}$, $1 - \frac{x^2}{1^2 q^2}$, $1 - \frac{x^2}{5^2 q^2}$, &c.

The successful pursuit of this line of inquiry would show that, in the present case, the extension of the laws of finite equations to equations involving interminate series is admissible; but it would do so at the expense of previously discovering those coefficients which were thought to have been found by the summation of the series of inverse powers.

The expressions for the log cosine and log sine may be developed directly by a process applicable to all series of the general form.

$$\theta x = 1 - c_1 x + c_2 x^2 - c_2 x^3 + \ \&c.$$

If, for shortness, we write

$$A = c_1 x - c_2 x^2 + c_3 x^3 - \ \&c.,$$

we have

$$-\log \theta x = \frac{A}{1} + \frac{A^2}{2} + \frac{A^3}{3} + \frac{A^4}{4} + \ \&c.$$

Here, from the expansions of the various powers of A, we have to collect the terms containing like powers of x.

A study of the character of these expansions enables us to write out the details of any one term separately from the rest. Thus, if we wish to get the term involving x^{10}, we have to consider all the combinations giving the tenth power; from A we have only the one form $c_{10} x^{10}$; from A^2, x^{10} is got in as many ways as 10 is decomposable into two parts, as $5+5$, $6+4$, $7+3$, $8+2$, $9+1$; from A^3 in as many ways as 10 may be divided into three parts, as $4+4+2$; $4+3+3$, and so on. Hence, altogether, the number of parts of which the term x^{10} is composed agrees with the number of ways in which 10 is decomposable.

The following simple scheme shows the decomposition of 10 and of all inferior numbers. The number of parts increases rapidly with the order of the term: for x^2 there are 2; for x^3, 3; for x^4, 5; for x^5, 7; for x^6, 11; for x^7, 15; for x^8, 22; for x^9, 30; and for x^{10}, 42 parts.

$1+1+1+1+1+1+1+1+1+1$
$1+1+1+1+1+1+1+1+2$
$1+1+1+1+1+1+1+3$
$1+1+1+1+1+1+2+2$
$1+1+1+1+1+1+4$
$1+1+1+1+1+2+3$
$1+1+1+1+1+5$
$1+1+1+1+2+2+2$
$1+1+1+1+2+4$
$1+1+1+1+3+3$
$1+1+1+1+6$
$1+1+1+2+2+3$
$1+1+1+2+5$
$1+1+1+3+4$
$1+1+1+7$
$1+1+2+2+2+2$
$1+1+2+2+4$
$1+1+2+3+3$
$1+1+2+6$
$1+1+3+5$
$1+1+4+4$
$1+1+8$
$1+2+2+2+3$
$1+2+2+5$
$1+2+3+4$
$1+2+7$
$1+3+3+3$
$1+3+6$
$1+4+5$
$1+9$
$2+2+2+2+2$
$2+2+2+4$
$2+2+3+3$
$2+2+6$
$2+3+5$
$2+4+4$
$2+8$
$3+3+4$

$$\begin{array}{r} 3+7 \\ 4+6 \\ 5+5 \\ 10 \end{array}$$

The order of these parts is thus simple; their coefficients also are readily found; thus for the part

$$(c_1x^1)^3(c_2x^2)^2(c_3x^3)^1 \text{ or } c_1^3 \,.\, c^2 \,.\, c_3^1 \,.\, x^{10} \,,$$

we observe that the number of its parts is 6, so that it must have come from A^6, as belonging to which power, its multiplier must be

$$\frac{1 \,.\, 2 \,.\, 3 \,.\, 4 \,.\, 5 \,.\, 6}{1 \,.\, 2 \,.\, 3 \,.\, 1 \,.\, 2 \,.\, 1} = 60 \,,$$

wherefore as coming from $\dfrac{1}{6}A^6$ it is

$$\frac{60}{6} \,.\, c_3^1 \,.\, c_2^2 \,.\, c_3^1 \,.\, x^{10} \,.$$

In this way it is a matter of mere labour to write out the parts of the term, and to sum them.

In the case of the logarithmic cosine this part becomes

$$+\frac{60}{6}\left(\frac{a^2}{1 \,.\, 2}\right)^3\left(\frac{a^4}{1 \,.\, 2 \,.\, 3 \,.\, 4}\right)^2\left(\frac{a^6}{1 \,.\, 2 \,.\, 3 \,.\, 4 \,.\, 5 \,.\, 6}\right)^1,$$

and for $\log \dfrac{a}{\sin a}$ the corresponding part is

$$+\frac{60}{6}\left(\frac{a^2}{1 \,.\, 2 \,.\, 3}\right)^3\left(\frac{a^4}{1 \,.\, 2 \,.\, 3 \,.\, 4 \,.\, 5}\right)^2\left(\frac{a^6}{1 \,.\, 2 \,.\, 3 \,.\, 4 \,.\, 5 \,.\, 6 \,.\, 7}\right).$$

For facilitating the multiplication of these denominators it is convenient to make a list of the continued products of the natural numbers, thus—

$$\begin{array}{rl}
(2) = & 2 \\
(3) = & 2 \cdot 3 \\
(4) = & 2^3 \cdot 3 \\
(5) = & 2^3 \cdot \cdot 5 \\
(6) = & 2^4 \cdot 3^2 \cdot 5 \\
(7) = & 2^4 \cdot 3^2 \cdot 5 \cdot 7 \\
(8) = & 2^7 \cdot 3^2 \cdot 5 \cdot 7 \\
(9) = & 2^7 \cdot 3^4 \cdot 5 \cdot 7 \\
(10) = & 2^8 \cdot 3^4 \cdot 5^2 \cdot 7 \\
(11) = & 2^8 \cdot 3^4 \cdot 5^2 \cdot 7 \cdot 11 \\
(12) = & 2^{10} \cdot 3^5 \cdot 5^2 \cdot 7 \cdot 11
\end{array}$$

$$
\begin{aligned}
(13) &= 2^{10}\cdot 3^{5}\cdot 5^{2}\cdot 7\cdot 11\cdot 13\\
(14) &= 2^{11}\cdot 3^{5}\cdot 5^{2}\cdot 7^{2}\cdot 11\cdot 13\\
(15) &= 2^{11}\cdot 3^{6}\cdot 5^{3}\cdot 7^{2}\cdot 11\cdot 13\\
(16) &= 2^{15}\cdot 3^{6}\cdot 5^{3}\cdot 7^{2}\cdot 11\cdot 13\\
(17) &= 2^{15}\cdot 3^{6}\cdot 5^{3}\cdot 7^{2}\cdot 11\cdot 13\cdot 17\\
(18) &= 2^{16}\cdot 3^{8}\cdot 5^{3}\cdot 7^{2}\cdot 11\cdot 13\cdot 17\\
(19) &= 2^{16}\cdot 3^{8}\cdot 5^{3}\cdot 7^{2}\cdot 11\cdot 13\cdot 17\cdot 19\\
(20) &= 3^{18}\cdot 3^{8}\cdot 5^{4}\cdot 7^{2}\cdot 11\cdot 13\cdot 17\cdot 19\\
(21) &= 2^{18}\cdot 3^{9}\cdot 5^{4}\cdot 7^{3}\cdot 11\cdot 13\cdot 17\cdot 19\\
(22) &= 2^{19}\cdot 3^{9}\cdot 5^{4}\cdot 7^{3}\cdot 11^{2}\cdot 13\cdot 17\cdot 19.
\end{aligned}
$$

As an example of the manner of carrying on the work, the computation of the coefficient of a^{14} (that is x^{7}) in the expression for log sec a, is subjoined.

Computation of term a^{14} in log sec a.

	Denominators.	Numerators.
$+\frac{1}{7}\left(\frac{a^2}{2}\right)^7$	$+2^7 \ldots 7$	$+2^4.3^5.5^2.7.11.13$
$-\frac{6}{6}\left(\frac{a^2}{2}\right)^5\cdot\left(\frac{a^4}{4}\right)^1$	$-2^8.3$	$-2^3.3^4.5^2.7^2.11.13$
$+\frac{5}{5}\left(\frac{a^6}{2}\right)^4\cdot\left(\frac{a^6}{6}\right)^1$	$+2^8.3.5$	$+2^3.3^3.5.7^2.11.13$
$+\frac{10}{5}\left(\frac{a^2}{2}\right)^3\cdot\left(\frac{a^4}{4}\right)^2$	$+2^8.3^2$	$+2^3.3^3.5^2.7^2.11.13$
$-\frac{4}{4}\left(\frac{a^2}{2}\right)^3\cdot\left(\frac{a^8}{8}\right)^1$	$-2^{10}.3^2.5.7$	$-2.3^3.5.7.11.13$
$-\frac{12}{4}\left(\frac{a^2}{2}\right)^2\cdot\left(\frac{a^4}{4}\right)^1\cdot\left(\frac{a^6}{6}\right)^1$	$-2^9.3^2.5$	$-2^2.3^3.5.7^2.11.13$
$+\frac{3}{3}\left(\frac{a^2}{2}\right)^2\cdot\left(\frac{a^{10}}{10}\right)^1$	$+2^{10}.3^4.5^2.7$	$+2.3.\ .7.11.13$
$-\frac{4}{4}\left(\frac{a^2}{2}\right)^1\cdot\left(\frac{a^4}{4}\right)^3$	$-2^{10}.3^3$	$-2.3^2.5^2.7^2.11.13$
$+\frac{6}{3}\left(\frac{a^2}{2}\right)^1\cdot\left(\frac{a^4}{4}\right)^1\cdot\left(\frac{a^8}{8}\right)^1$	$+2^{10}.3^3.5.7$	$+2.3^2.5.7.11.13$

	Denominators.	Numerators.
$+\frac{3}{3}\left(\frac{a^2}{2}\right)^1\cdot\left(\frac{a^6}{6}\right)^2$	$+2^9\ .\ 3^4\ .\ 5^2$	$+2^2.3\ .\ \ .7\ .11.13$
$-\frac{2}{2}\left(\frac{a^2}{2}\right)^1\cdot\left(\frac{a^{12}}{12}\right)^1$	$-2^{11}\ .\ 3^5\ .\ 5^2\ .\ 7\ .\ 11$	$-\ \ 7\ .\ \ .13$
$+\frac{3}{3}\left(\frac{a^4}{4}\right)^2\cdot\left(\frac{a^6}{6}\right)^1$	$+2^{10}\ .\ 3^4\ .\ 5$	$+2\ .3\ .5\ .7^2.11.13$
$-\frac{2}{2}\left(\frac{a^4}{4}\right)^1\cdot\left(\frac{a^{10}}{10}\right)^1$	$-2^{11}\ .\ 3^5\ .\ 5^2\ .\ 7$	$-\ \ 7\ .11.13$
$-\frac{2}{2}\left(\frac{a^6}{6}\right)^1\cdot\left(\frac{a^8}{8}\right)^1$	$-2^{11}\ .\ 3^4\ .\ 5^2\ .\ 7$	$-\ \ .3\ .\ .\ 7\ .11.13$
$+\frac{1}{1}\left(\frac{a^{14}}{14}\right)^1$	$+2^{11}.3^5.5^2.7^2.11.13$	$+1$
common denominator,	$2^{11}.3^5.5^2.7^2.11.13$	

− 16 216 200
+ 45 405 360
− 4 054 050
+ 6 006
− 3 063 060
+ 84 084
− 91
+ 210 210
+ 22 372 259
− 4 004
+ 1
+ 22 368 256

Hence the term is $\dfrac{22\ 368\ 256}{2^{11} \cdot 3^5 \cdot 5^2 \cdot 7^2 \cdot 11 \cdot 13} a^{14}$ which, on being simplified, becomes

$$\frac{2 \cdot 43 \cdot 127}{3^5 \cdot 5^2 \cdot 7^2 \cdot 11 \cdot 13} a^{14} = \frac{10922}{42567525} a^{14}.$$

In this way we get the following results :—

Nep. log sec $a =$

$$\frac{1}{2} a^2 + \frac{1}{2^2 \cdot 3} a^4 + \frac{1}{3^2 \cdot 5} a^6 + \frac{17}{2^3 \cdot 3^2 \cdot 5 \cdot 7} a^8 + \frac{31}{3^4 \cdot 5^2 \cdot 7} a^{10}$$

$$+ \frac{691}{2 \cdot 3^5 \cdot 5^2 \cdot 7 \cdot 11} a^{12} + \frac{2 \cdot 43 \cdot 127}{3^5 \cdot 5^2 \cdot 7^2 \cdot 11 \cdot 13} a^{14}$$

$$+ \frac{257 \cdot 3617}{2^4 \cdot 3^6 \cdot 5^3 \cdot 7^2 \cdot 11 \cdot 13} a^{16} + \frac{73 \cdot 43867}{3^8 \cdot 5^3 \cdot 7^2 \cdot 11 \cdot 13 \cdot 17} a^{18}$$

$$+ \frac{31 \cdot 41 \cdot 283 \cdot 617}{2 \cdot 3^8 \cdot 5^4 \cdot 7^2 \cdot 11 \cdot 13 \cdot 17 \cdot 19} a^{20} + \&c.$$

Nep. log $\dfrac{a}{\sin a} =$

$$\frac{1}{2 \cdot 3} a^2 + \frac{1}{2^2 \cdot 3^2 \cdot 5} a^4 + \frac{1}{3^4 \cdot 5 \cdot 7} a^6 + \frac{1}{2^3 \cdot 3^3 \cdot 5^2 \cdot 7} a^8$$

$$+ \frac{1}{3^5 \cdot 5^2 \cdot 7 \cdot 11} a^{10} + \frac{691}{2 \cdot 3^7 \cdot 5^3 \cdot 7^2 \cdot 11 \cdot 13} a^{12}$$

$$+ \frac{2}{3^6 \cdot 5^2 \cdot 7^2 \cdot 11 \cdot 13} a^{14} + \frac{3617}{2^4 \cdot 3^7 \cdot 5^4 \cdot 7^2 \cdot 11 \cdot 13 \cdot 17} a^{16}$$

$$+ \frac{43867}{3^{11} . 5^3 . 7^3 . 11 . 13 . 17 . 19} a^{18} + \frac{283 \cdot 617}{2 . 3^9 . 5^6 . 7^2 . 11^2 . 13 . 1 . 7 . 19} a^{20} + \&c.$$

The coefficients in the first series are multiples of the corresponding coefficients in the second series, the multiplier for the terms a^{2n} being $a^{2n} - 1$ or $(a^n - 1)(a^n + 1)$. Thus for a^2 the multiplier is $1 \cdot 3$; for a^4 it is $3 \cdot 5$; for a^6 it is $7 \cdot 9$, and so on; which is in accordance with the obvious law, that the sum of the nth inverse powers of the natural numbers, is $2n$ times that of the series of even numbers.

The law of formation of the coefficients in these series may be shown in the following manner. If the polynome

$$\phi x = 1_1 - c_1 x + c_2 x^2 - c_3 x^3 + c_4 x^4 - \&c.$$

be the continued product of factors $1 - r'x$, $1 - r''x$, $1 - r'''x$, &c., and if we multiply each term by its exponent with the sign changed so as to get

$$c_1 x - 2c_2 x^2 + 3c_3 x^3 - 4c_4 x^4 + \&c.$$

and divide this by the original polynome, developing the quotient in an interminate series,

$$d_1 x + d_2 x^2 + d_3 x^3 + d_4 x^4 + \&c.$$

the coefficient d_1 is the sum of the r', r'', r''', d_2 is the sum of their squares, $d_3{}^3 = 2r^3$, and so on; wherefore

$$\frac{1}{1} d_1 x + \frac{1}{2} d_2 x^2 + \frac{1}{3} d_3 x^3 + \frac{1}{4} d_4 x^4 + \&c.$$

is the logarithm of their continued product, that is the logarithm of ϕx. Now, the coefficients d_1, d_2, d_3 are formed from the successive equations

$$\begin{aligned}
0 &= \quad c_1 - d_1 \\
0 &= -2c_2 + d_1 c_1 - d_2 \\
0 &= +3c_3 - d_1 c_2 + d_2 c_1 - d_3 \\
0 &= -4c_4 + d_1 c_3 - d_2 c_2 + d_3 c_1 - d_4
\end{aligned}$$

and so on.

The application of this general method to our present series gives the coefficients with much less labour than the process previously detailed, because each result is useful in the subsequent steps; but the former has the advantage of independent computation. The one operation serves as a needful check upon the other.

Converting these coefficients into decimals, we have

Nep. log sec $a =$

$$\begin{array}{rrrrl}
& \cdot 50000 & 00000 & 00000 & 00000 \times a^2 \\
+ & 8333 & 33333 & 33333 & 33333 \times a^4
\end{array}$$

$$
\begin{aligned}
+ \quad & 2222\ 22222\ 22222\ 22222 \times a^{6} \\
+ \quad & 674\ 60317\ 46031\ 74603 \times a^{8} \\
+ \quad & 218\ 69488\ 53615\ 52028 \times a^{10} \\
+ \quad & 73\ 86029\ 60825\ 18305 \times a^{12} \\
+ \quad & 25\ 65805\ 74040\ 89150 \times a^{14} \\
+ \quad & 9\ 09896\ 49190\ 70739 \times a^{16} \\
+ \quad & 3\ 27793\ 02274\ 75478 \times a^{18} \\
+ \quad & 1\ 19564\ 55712\ 17762 \times a^{20}
\end{aligned}
$$

$$\text{Nep. log}\ \frac{a}{\sin a} =$$

$$
\begin{aligned}
& \cdot 16666\ 66666\ 66666\ 66667 \times a^{2} \\
+ \quad & 555\ 55555\ 55555\ 55556 \times a^{4} \\
+ \quad & 35\ 27336\ 86067\ 01940 \times a^{6} \\
+ \quad & 2\ 64550\ 26455\ 02646 \times a^{8} \\
+ \quad & 21377\ 79915\ 55769 \times a^{10} \\
+ \quad & 1803\ 67023\ 40053 \times a^{12} \\
+ \quad & 156\ 61391\ 32277 \times a^{14} \\
+ \quad & 13\ 88413\ 04937 \times a^{16} \\
+ \quad & 1\ 25043\ 59176 \times a^{18} \\
+ \quad & 11402\ 57560 \times a^{20}
\end{aligned}
$$

In order to make these formulæ useful in ordinary calculations, we must multiply all the coefficients by the modulus of denary logarithms. Thus—

Den. log sec $a =$

$$
\begin{aligned}
& \cdot 21714\ 72409\ 51625\ 91383 \times a^{2} \\
+ \quad & 3619\ 12868\ 25270\ 98564 \times a^{4} \\
+ \quad & 965\ 09884\ 86738\ 92950 \times a^{6} \\
+ \quad & 292\ 97643\ 62045\ 74646 \times a^{8} \\
+ \quad & 94\ 97798\ 19329\ 86290 \times a^{10} \\
+ \quad & 32\ 07711\ 90203\ 78068 \times a^{12} \\
+ \quad & 11\ 14315\ 27469\ 52792 \times a^{14} \\
+ \quad & 3\ 95163\ 02553\ 83690 \times a^{16} \\
+ \quad & 1\ 42358\ 70098\ 56471 \times a^{18} \\
+ \quad & 51926\ 22738\ 91936 \times a^{20}
\end{aligned}
$$

$$\text{Den. log}\ \frac{a}{\sin a} =$$

$$\begin{array}{lr}
 & \cdot 07238\ 24136\ 50541\ 97128 \times a^2 \\
+ & 241\ 27471\ 21684\ 73238 \times a^4 \\
+ & 15\ 31902\ 93440\ 30047 \times a^6 \\
+ & 1\ 14892\ 72008\ 02254 \times a^8 \\
+ & 9284\ 26020\ 85031 \times a^{10} \\
+ & 783\ 32402\ 98017 \times a^{12} \\
+ & 68\ 01655\ 83041 \times a^{14} \\
+ & 6\ 02980\ 12595 \times a^{16} \\
+ & 54305\ 74190 \times a^{18} \\
+ & 4952\ 07566 \times a^{20}
\end{array}$$

The application of these, as of all series of the same kind, to the construction of tables, is attended with grave inconvenience. This is well seen in the case of the series for the sines themselves; for although those be so convergent as to be applicable for any value of the arc, it is less laborious, and much more exact, to deduce the values of the sine from its well known properties. In the present case the convergence is so slow that the series can only be used for small arcs.

The computation of the canon of logarithmic sines by their help alone, would entail more labour than the simple plan of deducing the logarithm from the sine, even although we counted the making of the two previous canons as part of the work.

2. On *Stichocotyle nephropis*, a new Trematode. By J. T. Cunningham, Esq., B.A. Communicated by John Murray, Esq.

3. Scottish Vital Statistics. By Mr George Seton, Advocate, M.A. Oxon.

It is frequently remarked that the science of statistics, in its various branches, is, like the law, "gloriously uncertain," and accordingly, it is alleged that, from the same set of figures, two intelligent men can draw very different conclusions. The same

assertion may, perhaps even more truly, be made regarding *facts*, which, although considered somewhat "sair to ding," are very differently interpreted by different individuals.* Interested motives, preconceived opinions, and illogical conceptions constitute some of the principal causes of perverted conclusions; and both facts and figures are very liable to misrepresentation. Hence the tendency in many quarters to distrust the deductions drawn from figures of almost every kind, more especially in the columns of official reports and the prospectuses of commercial enterprises. Even among intelligent and educated men, some strangely confused ideas prevail respecting statistics, many such persons erroneously supposing that every class of numerical facts ought to possess an equal amount of certainty and precision, similar to what is produced by the abstract figures of an arithmetical process.

When regarded in the true and proper light, and after having been subjected to certain requisite modifications, the same series of figures cannot possibly admit of two inconsistent conclusions. On the present occasion, my remarks will be entirely confined to what are usually termed "Vital Statistics," as derived from the national Registers of Births, Marriages, and Deaths. The disregard of what may be termed *disturbing influences* is probably the most frequent cause of erroneous deductions from the published figures. Thus, in one town district, with a population of 20,000 persons, the mortality of the year is found to amount to 35 per 1000; while in another, with the same population, the mortality is only 20 per 1000. A casual reader is apt to jump to the conclusion that the former district is much more unhealthy than the other; whereas, if he took the trouble to reflect and inquire, he would pro-

* In one of his papers in the *Spectator* on "The Uncertainty and Absurdity of Public Reports," Steele refers to the very limited number of persons who *can* see or hear—that is, who can accurately report what they have seen or heard—either through incapacity or prejudice. After stating that he despises the man given to narration under the appellation of "a matter of fact man," he defines him as "one whose life and conversation is spent in the report of what is *not* matter of fact." Probably the ordinary estimate of the individual in question is somewhat different; but it cannot be denied that in many instances the force of a verbal description depends more upon the look, the voice, and the gesture than upon the words themselves, and accordingly a very erroneous impression may sometimes be derived from a colourless and undiscerning narration.

bably find that in the one district there was a large hospital or infirmary drawing cases from every corner of the country, and with an abnormally large mortality, while in the other there was nothing of the kind; or that, in the one, the condition of the house accommodation, drainage, and water supply was very faulty, and in the other quite the reverse. As in the case of deaths, very erroneous conclusions are apt to be drawn from the statistics of births and marriages. I propose to make a few observations on each of these three classes of events.

I. Births.—The periodical returns from two parishes, almost identical in population, social condition, occupation, and other circumstances, continue to present very different figures in the number of their respective births; and ordinary readers are very much perplexed by the published results. On inquiry, it is found that in one of the parishes the number of young married couples is exceptionally large, while in the other the proportion of bachelors and elderly married couples is much above the average. A large permanent *inequality in the numbers of the two sexes* is another manifest explanation of differences in the number of births. When we compare the number of these events reported from a parish in Orkney or Shetland with those occurring in an *inland* parish containing the same number of ordinary inhabitants, we can frequently account for the small proportion of the former by the circumstance of an unusual number of males having been absent at sea for a long period.

In a paper which I read before the Society last session, I made some explanatory observations upon the disproportionate numbers of illegitimate births in town and country districts respectively. The principal cause of their comparative paucity in the former is, no doubt, the *barren prostitution* of large centres of population. There, also, it is probable that at least a few illegitimate births escape registration.

The merely *temporary residence of the mothers* of illegitimate children is frequently adverted to by registrars of rural districts as unfairly swelling the number of these births; and where the domicile can be ascertained, it is duly entered in the register. Others occasionally allude to the circumstance of conception having

taken place elsewhere. Thus, the registrar of a Sutherlandshire parish, in a comparatively recent return, states that "the fathers of all the illegitimate children belong to Caithness, while the mothers are either servants or outworkers in the same county, who came home to be confined." In like manner, a Stirlingshire registrar states that no fewer than sixteen of the mothers of the twenty-seven illegitimate children registered in a certain quarter of the year 1871 were domestic servants who returned to their homes to give birth to their children. Unless, however, the fathers are to be regarded as solely responsible for the births in these two cases, the parishes in which the events occurred are hardly entitled to make an unqualified repudiation.

The existence of a *maternity hospital* in any district usually helps to increase the number of illegitimate births, and ought fairly to be taken into account in every comparative estimate of morality.

Again, the number of illegitimate births is frequently augmented by the *temporary residence of labourers* employed in the construction of railways and other public works. A few years ago, the proportion of illegitimate births in a certain parish in Perthshire rose from the normal ratio of about 10 to no less than 20 per cent., the formation of the Oban railway being the cause assigned by the registrar. A still higher fluctuation was reported from a similar cause by an Ayrshire registrar, in whose parish the ratio of illegitimacy amounted to no less than 30·3 per cent. as against 7·4 per cent. during the preceding quarter.

II. Marriages.—Many causes contribute to the fluctuation in the number of marriages in the same parish, as well as to the disproportion between the numbers in parishes similarly circumstanced. It need scarcely be remarked that the *state of trade* exercises a powerful influence on the matrimonial market. When work is abundant, wages liberal, and provisions cheap, the marriage rate is usually high; and accordingly the general prosperity and commercial activity of almost any district may be fairly inferred from the well-filled pages of the marriage register. This particularly applies to the great mining and manufacturing districts. Thus, the slackness of trade in Scotland during the years 1858, 1862, and 1867 caused the marriages to decline from 5 to 8 per cent.; while

the large increase of upwards of 1700 marriages in 1870, or nearly 8 per cent. above those of the previous year, indicated a marked return of commercial prosperity. *Scanty crops*, and still more frequently a *failure in the cod or herring fishings*, are constantly mentioned by registrars as accounting for a paucity of marriages; and in many instances the same result is attributed to the fact of large numbers of the working classes, in the prime of life, having temporarily left their homes owing to dulness of trade. Thus, not many years ago, the registrar of a Ross-shire parish reported that "in consequence of the steady falling off of the haddock and herring fishings, the third quarter had passed without any entry in the marriage register." On the other hand, about the same period, the registrar of Fraserburgh announced that the marriages in that parish had been 80 per cent. above the average of the five previous years, the herring fishing in July, August, and September having proved so very successful that "the value of fish caught, including casks and curing, had been set down at £130,000."

Another cause of fluctuation in the number of marriages is to be found in the *season of the year*. This is perhaps more observable in Scotland than in the other portions of the United Kingdom. On the north side of the Tweed, the month of *May* has always been unpopular among brides and bridegrooms; while the last day of the year, the month of June, and Martinmas term have long been very favourite periods for matrimonial contracts. An impression pretty generally prevails that May is an unlucky month for matrimony, and the origin of the idea has been assigned to the circumstance of Queen Mary's marriage to Bothwell having been celebrated in that month. A more satisfactory explanation has been offered in connection with the numerous changes of abode consequent on the occurrence of the *house term*, only a few days before the end of the month, thus naturally affecting the monthly average of marriages, which are largely augmented during the following month of June.* The annexed table, from the Report on the Scottish Census of 1871, shows, in the first column, the number of marriages registered in each month of the ten years ending 1870, while the second column exhibits the numbers as corrected for

* See Appendix.

January and December. The other ten months require no correction, seeing that the number of marriages contracted on the last day of each month and registered on one of the early days of the following month counterbalance each other.

Marriages in Scotland during each Month of the Ten Years 1861–70, *and their proportions to the Total Marriages.*

Months.	Marriages as registered each month.	Marriages corrected for December and January.	Proportion per 1000 each month, or per 12,000 per annum.	Percentage each month to total Marriages.
January, . .	26,219	16,579	888	7·39
February, . .	13,593	13,593	727	6·06
March, . .	12,707	12,707	680	5·67
April, . .	13,081	13,081	700	5·83
May, . .	10,889	10,889	583	4·86
June, . .	32,269	32,269	1,727	14·39
July, . .	22,038	22,038	1,179	9·83
August, . .	14,353	14,353	768	6·40
September, .	12,978	12,978	695	5·79
October, . .	14,435	14,435	772	6·44
November, .	22,475	22,475	1,203	10·02
December, .	29,185	38,825	2,078	17·32
Ten years, .	224,222	224,222	12,000	100·00

It will be observed that the four favourite months for marriage are December, June, November, and July, which respectively furnish 17·32, 14·39, 10·02, and 9·83 per cent., or more than one-half (51·56) of the total marriages; while the smallest number of marriages occurs in May, viz., only 4·86 per cent.—March, September, and April each furnishing less than 6 per cent.

The favourite *day* in Scotland for contracting marriage is the *last day of the year*, provided it does not fall on a Saturday or Sunday.* During the ten years in question no fewer than 12,000 of the 224,222 marriages contracted took place on the 31st of December—amounting to no less than 5·35 per cent.—a higher proportion than that of the entire month of May. As in France, the great annual holiday in Scotland is New-Year's Day, and as

* Very marked differences present themselves on the two sides of the Tweed with reference to the selection of particular days of the week for the celebration of the marriage ceremony. While our English neighbours continue to follow the customs of the Romish Church, the Scotch seem to be perceptibly influenced by those of the Puritans. Accordingly, it will be observed from the figures in

the accompanying festivities are frequently continued for several days, a marriage celebrated on the last day of the year enables the bride and bridegroom to enjoy a longer honeymoon than at any other season. The same results are observed, on a smaller scale, in connection with most of the great annual fairs in Glasgow, Dundee, and other large towns. Thus, in Glasgow, the average weekly number of marriages is more than quadrupled during the week of the yearly fair in the month of July.

The comparative percentages of marriages in *town and country districts* respectively must also be referred to. The registrars of the latter frequently allude to the practice of persons whose banns have been proclaimed in the country proceeding to some large town to be married; and as the event is recorded where it takes place, the marriage register of the parish of domicile is thus deprived of a good many entries. *Per contra,* however, it occasionally happens that denizens of the town resort to the country for the completion of the nuptial tie. During the Glasgow Fair holidays, for example, many young couples, whose banns have been previously published in Glasgow, go "down the water," as it is termed, for the purpose of being married.

Several of the northern registrars have referred to the *cost of rural weddings* as one of the causes of the ceremony taking place

the following table, applicable to the year 1862, and extracted from the Report on the Scottish Census of 1871, that the percentage of marriages celebrated in England and Scotland respectively on *Sunday* was 32 and 0·9, while those celebrated on *Friday* amounted to 2 and 43·3 per cent.

Number and Proportion of Marriages in Scotland and England during each day of the week for the year 1862, *deducting Marriages in Scotland on the last day of the year.*

Days of Week.	Scotland.		England.
	No. of Marriages.	Percentage to total Marriages.	Percentage to total Marriages.
Sunday, . .	184	0·9	32
Monday, . .	2501	12·9	21
Tuesday, . .	3418	17·6	11
Wednesday, .	1329	6·8	8
Thursday, .	2323	12·0	9
Friday, . .	8407	43·3	2
Saturday, . .	1270	6·5	17

elsewhere. Thus, little more than two years ago, in his return for the quarter ending December, the registrar of a Ross-shire parish reported that "the marriages are becoming fewer every year, but some belonging to the parish are married in the low-country towns to avoid the expense of a 'Highland wedding.'" In the return for the same quarter, an Inverness-shire registrar stated that "the excessive expense connected with rural weddings, to which all and sundry must be invited, induces parties to take advantage of their proximity to the town of Inverness, and have the ceremony performed there, where it can be done on a cheaper scale."

The circumstance of the *residence of a favourite clergyman* being in a different parish from that of the domicile of the parties frequently accounts for the limited number of entries in the marriage register. The registrar of one of the districts of Dundee reported, a few years ago, that comparatively few marriages were recorded by him, because the houses of the favourite ministers for performing the ceremony of marriage were situated beyond the bounds of his district. In the return for the same quarter, the registrar of Kirkintilloch stated that of sixteen couples whose banns had been proclaimed in that parish, only three were married in it; and in the case of one of the districts of Greenock, with a population of not less than 15,000 (?), about the same period, the total number of marriages registered during the year seldom exceeded thirty, on account of most of the residences of the officiating clergy, as well as the chapels of the Episcopalians and Roman Catholics, being situated in adjoining parishes. Towards the end of 1878, the registrar of St Clement's district, Dundee, made the following announcement in one of his quarterly returns:—"The death of the Rev. George Gilfillan will cause a decrease in the number of marriages registered in this district, as, from his popularity among the labouring classes, he was called on to perform the marriage ceremony oftener than any other Protestant minister in Dundee." Occasionally the figures of suburban marriage registers are augmented by the circumstance of the residences of some of the incumbents of city charges being at a little distance from their cures. Thus, the registrar of Cathcart recently reported that his marriages were in excess, "owing chiefly to the residence of Glasgow clergymen being in that parish, and the marriage ceremony frequently taking place in the minister's house."

As in the case of births, the relative numbers of bachelors and spinsters materially affect the matrimonial market. Thus, since 1870 the registrar of a small Inverness-shire parish has twice reported a blank marriage register at the close of the year, the cause ungallantly assigned by him being the "undue proportion of *old maids!*" Very similar results, however, are found even where swains are abundant. The registrar of an insular parish in Argyllshire very recently reported that the only marriage during an entire quarter was that of a tradesman from the south; adding that "though there is a large number of native bachelors, the inducements to marry appear to be awanting."

III. Deaths.—For many reasons, more or less obvious, the mortality returns present even greater contrasts than those applicable to births and marriages. Speaking generally, the number of deaths is materially influenced by the *density of the population;* but this circumstance has been so frequently adverted to, that it is unnecessary to produce any confirmatory evidence.* The normal mortality of a closely-packed population may, however, be sensibly lessened by the judicious introduction of sanitary improvements; and during the last twenty years many very gratifying results have been exhibited in some of our largest cities. In many country districts, however, where the blessings of pure air and abundant space have been vouchsafed, we frequently find that a deficient or faulty water-supply, inattention to cleanliness and ventilation, or the toleration of nuisances in the immediate vicinity of human dwellings, are the means of largely augmenting the number of deaths. In such a city as Edinburgh, which, for the purposes of the Registration Acts, is divided into five districts, very striking differences appear in their respective mortality returns. It cannot, of course, be expected that the ratio of deaths should be the same in the district of St Giles, embracing as it does many of the most crowded and insanitary sections of the city, as in that of St George, which is largely composed of the abodes of the wealthy, with their various advantageous

* The numbers of births and marriages are also considerably augmented by the density of the population, being highest in the eight principal towns, next highest in the large towns, lower in the small towns, and lowest of all in the rural districts. Some interesting illustrative details will be found in the Fifteenth Annual Report of the Registrar-General, applicable to the year 1869.

conditions, or in that of Newington, where the proportion of inhabitants to the area which they occupy is so much smaller than in any of the other districts.

I have already referred to the increase of what may be termed the natural mortality of any particular district by the existence of a *hospital or infirmary* within its bounds, and, in like manner, the number of deaths is considerably increased by large *lunatic asylums and poorhouses,* in both of which the mortality is abnormally high. In a single summer quarter, not many years ago, in one of the districts of Greenock, no fewer than fifteen of the deaths in the infirmary were of persons belonging to an adjoining parish. About the same period, in a Mid-Lothian parish, ten of the sixty-six persons whose deaths had been recorded were lunatics or paupers from other localities. The mortality of such districts as Bridgeton (Glasgow), St Giles' (Edinburgh), St Mary's (Dundee), Larbert (Stirlingshire), and many others, is largely augmented by the existence of hospitals, infirmaries, and other public institutions. In referring to the circumstance of the deaths being above the average, the registrar of Stirling, in his return for the third quarter of 1878, explained that the mortality of the district was considerably increased by the presence of the Combination Poorhouse (embracing several parishes), the Royal Infirmary for the county, the Military Hospital, &c. A similar augmentation is frequently found in some of the most salubrious country districts, which are habitually resorted to by *delicate persons in search of health,* such as Rothesay, Crieff, Grantown, Forres, &c. Nearer home, we find that the exceptionally low mortality of the district of Newington (already referred to) is considerably increased by the deaths of invalids temporarily resident at Morningside, in consequence of the genial climate of that favoured locality.

Weather, of course, exercises a potent influence on the mortality returns in every corner of the kingdom. The old proverb, " A green Yule makes a fat kirkyard," has long been disproved by the reports of the Registrar-General. When the weather is unseasonably mild, as during the past winter, sickness frequently prevails, but the mortality is materially lessened. On the other hand, the marked effect of a severe winter upon the lives of the old, the young, and the delicate has been repeatedly illustrated by the Registrar's

returns. During the ten years ending 1870 the coldest month was January, when the deaths, amounting to 69,206, reached their maximum, while the smallest number occurred in September, viz., 50,342. On the other hand, during the six preceding years (1855–60), both February and March proved colder months than January, and produced the highest mortality, viz., 36,917 and 36,525 deaths respectively. As in the later period, however, the mortality was lowest in September, when the deaths numbered 27,110. The effect of great heat upon bowel complaints and kindred diseases has been repeatedly pointed out. The relative deaths, however, are not generally sudden, the sufferers frequently lingering for several weeks; and accordingly many of the deaths are not recorded till the autumn. The influence of season upon phthisis and several other ailments is more or less marked; while in the case of diseases of the digestive and urinary organs the same effect is comparatively imperceptible.

In Ireland and elsewhere the *scarcity* and consequent *high price of food* has frequently exercised a powerful influence on the national mortality; but in Scotland, at least during recent years, no such effect has been noticed. On the contrary, while in 1868, with wheat at 63s. 9d. per quarter and potatoes at 137s. 6d. per ton, the deaths amounted to only 69,416, during the following year, when wheat had fallen to 48s. 2d. and potatoes to 99s. 6d., the deaths reached the high number of 75,875. Results somewhat similar were presented in the mortality tables applicable to the years 1866 and 1867, when prices considerably differed.

It is hardly necessary to refer to the influence of *epidemics* on the public mortality, more especially cholera, smallpox, influenza, scarlet fever, and measles, from most of which we have been comparatively free for a good many years.

Lastly, the nature of the *occupations of the inhabitants* of any district has no inconsiderable effect upon the number of deaths—miners, fishermen, and the followers of other hazardous avocations being specially subject to untimely ends. In consequence of the frequent explosions in coal-pits, or the results of severe gales, the death register of many a rural parish, with a moderate average mortality, is obliged to be largely augmented. Thus, of the 247 deaths recorded in the parish of Blantyre in the last quarter of

1877, no fewer than 206 were caused by the explosion at the local colliery on the 22nd October of that year. Again, in the summer quarter of 1871, 17 of the 25 deaths recorded in the small Ross-shire parish of Avoch were caused by drowning, 3 men having been lost on the 16th of May when dredging for oysters; while 4 men and 10 women, all belonging to the fishing population, were drowned by the upsetting of an overcrowded coble. Of the 147 deaths registered in the parish of Eyemouth, Berwickshire, in the last quarter of 1881, no fewer than 129 were those of the unfortunate fishermen who perished in the fearful storm on the 14th of October of that year. They were all in the prime of life, 73 of them being married.

Several other disturbing influences might have been indicated in the case of each of the three events under consideration; but probably enough has been stated to show that considerable modifications ought, in many instances, to be made when we deal with figures illustrative of Scottish Vital Statistics.

APPENDIX.

Marriage Seasons in England.

"In London the close of the season among the higher classes is a matrimonial epoch; among the working classes the festivals of Whitsuntide and Christmas and the season of Lent exert some influence, so do the terms of service, which vary in different counties. The geniality of spring is perceptible; but Lincolnshire is the only county in which the spring weddings exceed the autumn weddings in number. The accumulations of autumn supply a store of food, and the harvest wages of the young swains in agricultural districts are often wisely invested in the furniture of a cottage: it has already been shown that workpeople are influenced in marriage by economic conditions and prospects.

"It might be supposed that marriages take place indifferently on any day of the week. But it is not so. Few marriages are celebrated on a Friday. Now Friday was in former times the day which would be especially devoted to these celebrations, as is implied by the names *Dies Veneris* of the Latins, and Friday, the day of the Saxon goddess Friga.

"This day was chosen by the early Church, perhaps partly in opposition to Paganism, as a day for carnal mortification. It was the day of the crucifixion of Christ; and hence the festive Friday of the Saxons, and the day especially under the star which astrologers held was most fortunate, fell into the category of 'unlucky days.' Seamen will not sail, women will not wed, on a Friday so willingly as on other days of the week. The Sun, Moon, and Saturn have gained by this silly superstition. Half the weddings are celebrated on Sunday and Monday; Saturday has more than its average number, and in the southern as well as the northern counties the Saturday marriages are the most numerous. It has been suggested that the pocket of the workman who has no account at the bank for savings, and lives on weekly wages, is often empty on Friday, which lays his mind open to gloomy omens, and indisposes him, while on Saturday he is exhilarated by the money which he throws into circulation on the three following days. Economy of time is an alleged motive for Sunday weddings."—*Report of the Registrar-General of England*, 1866.

"In England and Wales as a whole, and also in the individual counties without exception, there are fewer marriages in the first quarter than in any other. The maximum quarter, both in the entire country and, with three exceptions, in each county, is the fourth; while between the second and third there is but little difference, the second, however, having in the long run the preference. The three counties which are exceptions to the otherwise universal rule of the maximum falling in the Christmas quarter are Herefordshire, Shropshire, and, in a notable degree, Lincolnshire, in each of which, on an average of seven years (1875–81), the maximum fell in the second and not in the fourth quarter. Disregarding such exceptions, for which local explanations are probably to be found, the predominance of the fourth quarter is, as a rule, much more marked in purely agricultural counties than elsewhere; presumably because in agricultural districts the fourth quarter is a period of comparative leisure, whereas in industrial or, speaking generally, in urban districts there is much less distinction between one season of the year and another as regards occupation.

"In this country the marriages are only abstracted by quarters; but, in order to afford means of comparison with those foreign

countries in which the marriages are abstracted by months, they have been this year taken out in greater detail for a single county, viz., Gloucestershire, and for a single large town, viz., Manchester. The first two columns in the following table give the results, the months having been reduced to an equality as regards number of days. Other columns are added, giving the figures for some other countries :—

Marriages in each Month per 1000 *in Year.*

Month.	Gloucestershire, 1881.	Manchester, 1881.	Scotland, 1861–70.	German Empire. 1872–80.	Denmark, 1875–79.	Norway. 1876–78.	Switzerland, 1876–78.	France, 1876–79.	Italy. 1876–78.
January, .	52	75	74	80	44	62	60	101	99
February, .	71	73	61	99	50	45	102	120	142
March, . .	69	56	57	46	67	55	69	43	73
April, . .	99	86	58	98	95	85	96	85	86
May, . .	71	64	49	103	137	73	114	91	72
June, . .	90	111	144	77	74	127	81	94	65
July, . .	79	73	98	70	56	109	71	80	53
August, . .	78	94	64	57	44	47	64	60	60
September, .	83	90	58	78	56	66	74	73	74
October. .	106	87	64	106	111	116	95	91	81
November, .	76	76	100	124	165	118	111	111	101
December, .	126	115	173	62	101	97	63	51	94

"The county of Gloucestershire, comprising, as it does, the bulk of the great town of Bristol, as well as a large agricultural population, may be taken as fairly representing the total of England and Wales; and it was selected because, as a matter of fact, the distribution of its marriages by quarters was found to correspond very closely with the distribution in the country at large. It will be noticed that the months in which most marriages occurred were December, October, April, and June. The excesses in December, April, and June were due to the festival periods of Christmas, Easter, and Whitsuntide respectively; while the excess in October marks the period of leisure, and of cash in the labourer's pocket, which follows the close of harvest-time. This excess in October would doubtless have been still more marked had a purely agricultural country been selected; for in the completely urban population of Manchester no such excess in October is noticeable, whereas the festival months of Christmas and Whitsuntide show high figures. In the town the

Whitsuntide marriages, in June, were much more numerous than the Easter marriages, in April; whereas in the county the reverse was the case, a difference which may be attributed to the fact that the agricultural population was busy in June with the hay. In both town and county the marriages in May were below the average number in the other months, May being for some reason or other very generally regarded as a month of ill-omen for wedlock. The feeling against marrying in May is not easy of explanation. It is not common to all countries. On the contrary, in Germany, in Denmark, and in Switzerland this month appears from the table to be a favourite time for weddings. That it is attributable to May being 'the Virgin's month' seems scarcely compatible with the fact that in Catholic France, where such a cause would be expected to have much more influence than in Protestant England, the May marriages are slightly in excess. Not impossibly the custom may be a survival from Roman times; for in ancient Rome also it was deemed to be unlucky to wed in May, it is said, because the Lemuria, or Festival of the Departed Souls, was held in that month.

'Mense malas Maio nubere vulgus ait.'—Ovid."

—*Report of the Registrar-General of England*, 1883.

4. Experiments on the Chief Disinfectants of Commerce, with a view of ascertaining their Power of Destroying the Spores of the *Anthrax bacillus*. By A. Wynter Blyth, Medical Officer of Health and Public Analyst. Communicated by Prof. Turner.

The following paper gives the result of a considerable number of experiments made in 1883, the object of which was to ascertain whether any of the disinfectants in popular use had a "germicidal" action or not.

Very few have distinguished between the action of a *germicide* and that of a *disinfectant*. If fungus spores are steeped for a certain time in some powerful chemical solution, and then, on being *perfectly freed* from the solution by washing or otherwise, placed in any soil whatever, neither grow nor exhibit any life manifestation, we are justified in saying that the spore has been

destroyed, that its life has departed, and that the chemical solution is a true germicide; while if, on the contrary, although while in the solution the spore did not grow, yet, on being placed on suitable soil, there is either feeble or strong growth, in that case, although the solution may have disinfectant properties, it is not a germicide.

Much more has been done to show the disinfectant than the germicidal properties of substances. The labours of Angus Smith, Crace Calvert, Bucholz, and other workers have studied the inhibition of fungoid growth and of putrefaction, the destruction of odours, and the decomposition and fixing of noxious gases; so that further observations on the same lines would scarcely do more than confirm facts generally accepted.

But the action of chemical agencies on those minute particulate substances which are regarded as the *materies morbi*, or seeds of zymotic and parasitic diseases, have been but little investigated. Here is a field for investigation of almost illimitable extent, but nevertheless one in which we have already firm paths and footholds across the morass of theory and conjecture, as, for example, in Gerlach and Franck's experiments on the virus of glanders, Ledra on that of ovine variola, and Braidwood and Vacher on the lymph of vaccine.

Of all moderns who have directed their attention to disinfectants, Dr Koch stands chief; and his masterful monograph, "Ueber Desinfection" (published in *Mittheilungen aus dem Kaiserlichen Gesundheitsamte herausgegeben*, von Dr Struck, Berlin, 1881), will long remain an example and guide to future explorers.

In my own experiments I have followed out in principle, although not in detail, Koch's method.

Koch's observations were on the *Anthrax bacillus*, and at the commencement of my experiments no organism seemed so perfectly adapted for the trial of the germicide power of disinfectants, for—

(1) The morphology and life history of the *Anthrax bacillus* has been worked out with some completeness.

(2) When necessary, its vitality may be tested by inoculation.

(3) It exists in two states—the thread form, readily attacked by chemical and physical agencies, and the spore form, destroyed with great difficulty.

The advantages just cited, as well as the experiments of Koch, were sufficient to induce me to also select the *Anthrax bacillus* for the purpose of ascertaining the relative value of disinfectants.

Cultivation of Anthrax.—Dr Klein placed at my disposal a small supply of *Anthrax bacilli* in the spore state, and I had the advantage of studying his admirable paper * (Eleventh Annual Report of the Local Government Board), in which he has given full details of an improved method of cultivation.

A large air-bath was set up, and all flasks, beakers, and pipettes heated for many hours to about 500° Fahr. Similarly the cotton-wool used was disinfected by a dry heat, the heat being carried to nearly the singeing point.

As in Dr Klein's method, pork as lean as possible, after suitable division, was boiled in water, the broth filtered through a sieve, and then the supernatant fat separated by means of a separating funnel. The broth was next accurately measured, and 10 c.c. or 50 c.c., titrated by d. n. soda, using as an indicator phenol-phthalein. In this way the precise acidity was known, and from the data thus obtained it was easy to exactly neutralise the remaining bulk. After neutralisation with soda, the broth was again boiled for some time, and then filtered hot into a previously sterilised flask. From this stock flask the cultivation flasks were charged with from 20 to 30 c.c. of the broth.

The cultivation flasks had bulbs of about 70 c.c. capacity, the bottoms were flat, and the necks from four to five inches long, and narrow; they were charged by means of a sterilised pipette, and then plugged for at least three inches with a cotton-wool plug. After plugging, the flasks were immersed in a water-bath, so that only about an inch of the neck was above the surface, and the water kept boiling for many hours. This method answered very well, and seemed to me an improvement on the usual plan of directly boiling the broth in the flask. After this process the flasks thus charged were placed in an incubator thirty at a time, and kept for three days and nights at the temperature of the blood. Those that remained clear were then considered sterilised, those showing the least turbidity were rejected.

* "On the Relation of Pathogenic to Septic Bacteria, as illustrated by Anthrax Cultivation," by E. Klein, M.D., F.R.S. Supplement containing the Report of the Medical Officer.

The incubator was a copper air-bath supplied with a Page's gas regulator; it was found to automatically regulate the temperature within half a degree.

On similar principles Dr Klein's "*Pork-gelatin*" was prepared.

I also hit upon a plan of *albuminising* a broth, which seems likely to be useful. A fresh hen's egg was taken, a very small hole drilled in the shell, and then a pipette previously sterilised thrust into this hole through the membrane into the albumin, and the albumin sucked up, and then added to the broth, by momentarily removing the cotton-wool plug, and allowing the required quantity to flow in; a liquid is obtained by these simple means, which in the majority of instances keeps fresh without odour or turbidity, although submitted to a cultivation temperature for days, and is more like a *fluid tissue* than any cultivation fluid hitherto recommended. It seems pretty certain that so long as the shell and membrane of what is popularly called a fresh egg is intact, there are no parasitic germs within.

To infect any of these *soils*, a glass rod was drawn out very thin, the end tipped with sealing wax, and to the hot sealing wax a minute *fluff* of cotton-wool was made to adhere to the wax; and this rod was plunged into the anthrax holding fluid, so as only to immerse the sealing wax; having thus charged the threads or "fluff," the plug of one of the flasks was loosened, the thin rod passed rapidly down, and broken off short against the bottom of the flask, at the same time again plugging firmly; in this way the infecting of a flask was accomplished so rapidly that the accidental admixture of air germs was reduced to a minimum.

To ascertain the germicide power of a disinfectant, the little thin rod, with its small bead of sealing wax, and the "fluff" which had been contaminated by anthrax, was placed in the disinfectant for certain known periods of time, then removed and plunged into strong alcohol, into ether, or into previously boiled distilled water, according to the composition of the disinfectant, so as to dissolve out as far as possible the film of the disinfectant adhering to the wool. This having been accomplished, a flask of broth was infected in the manner already described, and the flask submitted to the heat of the incubator. If the broth remained perfectly clear, then the inference was that the disinfectant had killed the

spores; any growth or turbidity was submitted to microscopical examination.

A few experiments were made after the manner of Koch on nutrient gelatin, but it was not found so convenient as fluids. Although the microscope was in each case employed, I think all those who have worked at the subject will agree with me, that in perfectly normal cults, a little practice enables the anthrax cult to be distinguished by the naked eye from all other cults whatever.

Carbolic Acid.—The carbolic acids experimented upon were Calvert's No. 1, and the dark carbolic acid of commerce, containing tar oils and much foreign matter; Calvert's carbolic acid powder was also tested.

Calvert's Carbolic Acid No. 1.—A 1 per cent. solution in water of this acid was made, and the anthrax spores soaked in it, in the way detailed and then cultivated in the pork broth.

	Time during whicht he glass rod with its spores rested in the disinfectant.	Result.
1 per cent.	10 minutes.	Active growth in twenty-four hours.
„	1 hour.	do.
„	24 hours.	do.

Hence 1 per cent. of carbolic acid seemed to have no influence on anthrax spores, not even delaying the growth, for no decided difference between the disinfected cult and a cult not disinfected could be distinguished.

Experiment with 5 *per cent. Solution of Carbolic Acid.*

Time during which the glass rod with its spores remained in the disinfectant.	Result.
10 minutes.	After twenty-four hours, growth evident, but not anything like so plentiful as in the "control" flask; in four days growth luxuriant.
20 minutes.	Do.
4 hours.	No growth in twenty-four hours; after forty-eight hours, slight development; in four days a good growth.

Experiments with a 10 per cent. Solution.

Time during which the glass rod with its spores remained in the disinfectant.	Result.
20 minutes.	The "fluff" was freed by alcohol from the adhering film of carbolic acid; growth was delayed, but by the end of four days there was a good growth.
4 hours.	No growth in twenty-four hours; after forty-eight hours there was an appearance of some of the spores being active; in a few days a scanty growth was noticeable.
24 hours.	No growth.

Experiment with a 25 per cent. Solution in Alcohol.

Time during which the glass rod with its infected "fluff" remained in the disinfectant.	Result.
6 hours.	After twenty-four hours some development, and in four days a good growth.
24 hours.	No growth.

Dr Klein kindly experimented with my 10 per cent. solution on a guinea-pig; but although I wns unable to cultivate the spores successfully after twenty-four hours' soaking, the guinea-pig died of typical anthrax poisoning in two days.

Experiment with the Undiluted Acid.

Spores soaked for twenty-four hours in the undiluted acid did not afterwards develop.

Cresylic Acid.—A 25 per cent. solution of cresylic acid in alcohol acting on anthrax spores for twenty-four hours only delayed the growth. On the "fluff" being placed in a sterilised broth, there was no turbidity for twenty-four hours; while in the "control" the growth was evident and strong; afterwards a few threads slowly developed. By the end of four days the liquid was quite turbid.

Similar results were obtained by cultivating on "gelatin-pork."

Carbolic Acid Powders.

Since it seemed improbable that merely sprinkling the powder on the infected "fluff" would reach all the spores, the powder was added in weighed quantities to water, and was also made into a paste with water, and in the paste the glass rod containing the infected rods allowed to remain for various periods of time.

Calvert's Pink Carbolic Acid Powder, in water 5 *per cent.*—The spores acted on by this disinfectant for twenty-four hours were removed and cultivated on gelatin-pork as well as in broth. In each case growth, as compared with a comparison cult, was delayed; but by the end of four days the growth was luxuriant.

On making a paste with water, and allowing the spores to rest in the paste, even so long as twenty-four hours, no germicide effect was noticeable. As before, the growth was delayed.

Other carbolic acid powders were obtained from various firms, and tested, with no better result.

Liquor Carbonis Detergens.—This is a solution of certain coal-tar products in spirit. It forms with water an emulsion.

Added to water in the proportion of 5 per cent., it had but feeble influence in preventing the subsequent growth of anthrax.

A 10 per cent. solution, acting for four hours, distinctly retarded growth; for the spores, whether on gelatin-pork or in the broth, did not commence developing for twenty-four hours.

Undilated "liquor carbonis detergens," acting for four hours, arrested future growth.

Jeyes' Fluid.—Apparently a solution of various principles derived from coal-tar. It forms a thick emulsion with water.

It was necessary in this instance, after soaking the infected threads in the liquid, to free it from the thick emulsion by alcohol.

Four experiments showed that in a 5 per cent. solution—that is, such a solution as in practice might be used—it was not an efficient germicide.

Jeyes' Powder bears the same relation to Jeyes' liquid as the carbolic acid powders to carbolic acid.

The powder was made into a paste with water, but seemed to have no definite effect on the anthrax spores. Growth after twenty-four hours' cultivation was active.

Pixene.—This is a preparation which is said to be a solution of the principles of wood-tar. It has a strong empyreumatic odour, and forms an emulsion with water. Undiluted pixene seems to destroy the anthrax spores if allowed to act on them for twenty-four hours.

A 10 per cent. solution in water, acting on the spores for twenty-four hours, delayed gowth, but it was ultimately active.

In this case, as in all the tar products, it was found necessary to be very careful to completely free the "fluff" from the disinfectant. In my earlier experiments with pixene, when I did not wash the spores sufficiently, I gave a higher value to it than it really possessed. This was owing to the inhibitory power which small quantities of the tar products exercise on the growth of anthrax when actually present.

"Sanitas" Fluid.—The fluid is said to contain peroxide of hydrogen, thymol, camphoric acid, and terebene.

Spores soaked in the fluid for twenty-four hours afterwards grew freely when placed on suitable soils.

Sanitas Emulsion.—The spores placed in sanitas emulsion were delayed in growth, for there was no development for twenty-four hours. In forty-eight hours there was a feeble growth. Ultimately it was luxuriant.

Sanitas Oil.—This gave entirely similar results.

Sanitas Powder had no influence whatever on the growth of anthrax.

Morgan's Fluid, which contains sulphate of copper and zinc, with other ingredients in solution, was experimented with in the diluted and undiluted form; but in neither did it seem to have the slightest influence on the life of the spore.

Sulphate of Iron, which has been recommended to disinfect typhoid excreta, was experimented with in like manner. A saturated solution was made by boiling a large quantity with water, and then allowing it to cool.

Here again in no case was any destructive influence on the life of the spores observed.

Sulphate of Copper was also dissolved, and made of strengths from 5 per cent. up to saturation; but the spores were in no way attacked, although allowed to remain in the liquid for twenty-four hours.

Sulphate of Zinc gave an entirely similar result.

Chloride of Zinc.—Koch has given a very unfavourable verdict with regard to zinc chloride in one of his experiments. Anthrax spores grew well after a month's sojourn in a 5 per cent. solution.

Experiments were made with solutions of 1 per cent., 5 per cent., and 25 per cent. solutions.

I found the short steeping of an hour in a 1 per cent. solution stimulating the subsequent growth of the spores, the vegetation at the end of twenty-four hours being more active than in the comparison liquid.

Steeping the spores for twenty-four hours in a 5 per cent. solution did not seem to exert any influence on their development.

Steeping the spores in a 25 per cent. solution arrested the life of the spores, that is, so far as artificial cultivation is concerned.

Chloride of Zinc and Thymol.—Thymol was shaken up with water, and the thymol water thus obtained used as a solvent for zinc chloride, the solutions being made up to 1, 5, and 25 per cent. strength. In each case the behaviour was the same as in that of the pure solutions of zinc chloride, the addition of thymol in no way adding to or diminishing the action.

Perchloride of Iron.—Various strengths of a solution of ferric chloride in water were made from 1 up to 25 per cent.; but in no single case did a twenty-four hours' steeping of the spores destroy their vitality. With the stronger solution the vegetation was late, but ultimately luxuriant. With 1 per cent. solution the development was more rapid than usual, the growth being, as it were, stimulated.

Terebene.—A sample of terebene, said to be pure, had no effect on the spores; but on examination the so-called terebene was found to contain 70 per cent. of unchanged turpentine.

Another sample, which was certainly pure, gave better results. Spores soaked twenty-four hours in this terebene did not grow in sterilised broth.

A solution of the terebene in strong alcohol, so as to be exactly 10 per cent., experimented with as in the former case, delayed the growth, but it was ultimately luxuriant.

The terebene which seemed to have germicidal powers was further experimented with by Dr Klein. Spores soaked in it twenty-four

hours killed a guinea-pig, the animal dying of typical anthrax within four days.

Mercuric Chloride.—A 1 per cent. solution acting for twenty-four hours seemed to destroy the spores—that is, they did not grow in sterilised solutions. Nevertheless spores thus treated, on injection by Dr Klein into a guinea-pig, destroyed it within four days, with all the symptoms of typical anthrax.

The conclusions to be drawn from this research are that anthrax in the *spore* state, instead of being a suitable "reagent" for testing the *germicidal* powers of disinfectants, is so extraordinary in its powers of resistance to chemical agencies, that few solutions attack it, and those that have any influence must be used in a state of concentration, which in ordinary disinfecting operations could never be attained.

PRIVATE BUSINESS.

The following were balloted for, and declared duly elected Fellows of the Society:—Professor J. S. Nicholson and the Rev. J. S. Black.

Monday, 19th May 1884.

ROBERT GRAY, Esq., Vice-President, in the Chair.

The following Communication was read:—

1. Sur la Réduction des Intégrales Hyperelliptiques, extrait d'une lettre adressée à M. le Professeur Chrystal, *par* M. Hermite.

J'ai montré dans mon *Cours d'Analyse de l'École Polytechnique*, comment le procédé élémentaire d'intégration des fractions rationelles peut-être modifié de manière à donner l'intégrale lorsqu'elle est algébrique et ne contient pas de logarithmes, sans avoir d'équations a résoudre. Une question toute semblable se pose à l'égard des intégrales de la forme $\int \frac{P dx}{Q\sqrt{R}}$, ou P, Q, R, sont des polynômes entiers en x, et j'en ai exposé la solution dans un article du *Bulletin des Sciences Mathématiques* de M. Darboux

(C. vii. 1883). Mais la méthode que j'ai donnée peut être présentée sous une forme plus facile et plus simple ; c'est ce que je me propose de montrer, et avant d'aborder les intégrales hyperelliptiques, je considérerai d'abord celles des fractions rationelles $\frac{P}{Q}$.

Supposons que par la théorie élémentaire des racines égales, on ait mis le dénominateur sous la forme suivante :

$$Q = A^{a+1}B^{b+1}\ldots\ldots L^{l+1},$$

ou les polynômes $A, B, \ldots\ldots L$, n'ont que des facteurs simples : et faisons,

$$\frac{P}{Q} = \frac{G}{A^{a+1}} + \frac{H}{B^{b+1}} + \ldots\ldots + \frac{I}{L^{l+1}},$$

$G, H, \ldots I$, désignant encore des polynômes entiers.

Je considère l'intégrale $\int\frac{Gdx}{A^{a+1}}$, et j'observe que A et sa dérivée A', n'ayant pas de facteurs communs, on peut poser :

$$G = MA - aNA',$$

M et N étant des polynômes entiers. Cela étant, nous obtenons la formule suivante de réduction :

$$\int\frac{Gdx}{A^{a+1}} = \frac{N}{A^a} + \int\frac{(M-N')dx}{A^a},$$

qui se vérifie immédiatement par la différentiation ; et qui sera applicable, tant que l'exposant a ne sera point nul.

Soit donc $F = AB\ldots\ldots L$; $F_1 = A^aB^b\ldots\ldots L^l$: on en conclut de proche en proche l'expression suivante, ou Π et Φ désignent des polynômes entiers,

$$\int\frac{Pdx}{Q} = \frac{\Pi}{F_1} + \int\frac{\Phi dx}{F},$$

et quand l'intégrale est algébrique et sans logarithmes, on a identiquement : $\Phi = 0$.

Envisageons maintenant les intégrales hyperelliptiques $\int\frac{Pdx}{Q\sqrt{R}}$; et distinguant dans le dénominateur Q les facteurs simples premiers à R, que je nomme $A, B, \ldots\ldots$; et les facteurs appartenant a R, que je nomme $S, T, \ldots\ldots$: je ferai encore

$$\frac{P}{Q} = \frac{G}{A^{a+1}} + \frac{H}{B^{b+1}} \cdots\cdots + \frac{J}{S^s} + \frac{K}{T^t} + \cdots\cdots$$

observant maintenant que A n'ayant que des facteurs simples, et étant premier avec R, je puis écrire :

$$G = MA - aNRA'.$$

Soit encore

$$D_x(N\sqrt{R}) = \frac{N_1}{\sqrt{R}}$$

ou N_1 est évidemment un polynôme entier, on obtient la formule de réduction

$$\int \frac{Gdx}{A^{a+1}\sqrt{R}} = \frac{N\sqrt{R}}{A^a} + \int \frac{(M-N_1)dx}{A^a\sqrt{R}}.$$

Faisons ensuite : $R = SU$; en admettant, comme on le doit, que R n'ait que des facteurs simples, de sorte que S et US′ soient sans diviseurs communs, j'écrirai :

$$J = MS - (s - \tfrac{1}{2})NUS'$$

et nous aurons

$$\int \frac{Jdx}{S^s\sqrt{R}} = \frac{N\sqrt{R}}{S^s} + \int \frac{(M-N_1)dx}{S^{s-1}\sqrt{R}}.$$

Cette nouvelle formule de réduction, dans laquelle j'ai fait

$$D_x(N\sqrt{U}) = \frac{N_1}{\sqrt{U}},$$

se vérifie en différentiant, comme la précédente ; et si l'on remarque qu'elle ne souffre pas d'exceptions, qu'elle est applicable en supposant $s = 1$, on parvient à la conclusion suivante. Posons, en excluant les facteurs S, T, ... qui appartiennent à R,

$$F = AB \cdots\cdots ;$$

puis

$$F_1 = A^aB^b \cdots\cdots S^sT^t \cdots\cdots$$

on aura cette expression de l'intégrale proposée, dans laquelle Π et Φ représentent des polynômes entiers,

$$\int \frac{Pdx}{Q\sqrt{R}} = \frac{\Pi}{F_1} + \int \frac{\Phi dx}{F\sqrt{R}}.$$

Un dernier pas nous reste à faire ; soit E_1 la partie entière de la

fraction rationelle $\frac{\Phi}{F}$, l'intégrale $\int \frac{E_1 dx}{\sqrt{R}}$ se réduit en posant

$$\int \frac{E_1 dx}{\sqrt{R}} = M\sqrt{R} + \int \frac{N dx}{\sqrt{R}},$$

et déterminant le polynôme M de sorte que le degré de N soit le plus petit possible. On reconnaît ainsi qu'il faut prendre pour M la partie entière du développement, suivant les puissances descendantes de la variable, de l'expression $\frac{1}{\sqrt{R}} \int \frac{E_1 dx}{\sqrt{R}}$.

Nommons r le degré de R, et n le degré de N, nous aurons donc la condition

$$\frac{r}{2} - 1 = n - \frac{r}{2} + 1 ;$$

d'ou
$$n = r - 2 .$$

Les résultats que je viens d'établir succinctement conduisent à la notion importante des fonctions de première, de seconde, et de troisième espèce. Il suffit d'y joindre en effet la substitution linéaire $x = \frac{p+qt}{1+t}$, par laquelle on transforme un polynôme R de degré pair, dans l'expression $\frac{R_1}{(1+t)^2}$, où R_1 est de degré impair $r-1$.

Admettant donc que R soit de degré impair, les fonctions de première espèce seront les quantités $\int \frac{x^k dx}{\sqrt{R}}$, ou $k = 0, 1 \ldots \frac{r-3}{2}$, qui sont finies pour x infini, les fonctions de seconde espèce celles où $k = \frac{r-1}{2}, \frac{r+1}{2}, \ldots\ldots\ldots r-2$, qui sont infinies avec x: et les fonctions de troisième espèce, les quantités $\int \frac{dx}{(x-a)\sqrt{R}}$.

Une remarque encore en terminant, sur la substitution $x = \frac{p+qt}{1+t}$, qui fait disparaître les puissances impaires dans un polynôme du 4^{me} degré : $R(x) = A(x-a)(x-b)(x-c)(x-d)$. Des équations, données dans mon *Cours de la Faculté*, p. 8 :

$$\frac{a-p}{q-a} = -\frac{b-p}{q-b}, \quad \frac{c-p}{q-c} = -\frac{d-p}{q-d},$$

j'ai remarqué qu'on tire facilement celle-ci :

$$\frac{1}{p-a}+\frac{1}{p-b}-\frac{1}{p-c}-\frac{1}{p-d}=0$$

de sorte que l'une de ses racines donne p, et l'autre q. Or on reconnait que a, b, c, d, étant des quantités réelles rangées par ordre de grandeur, cette équation aurait une racine entre a et b, et une seconde entre c et d. Et si l'on suppose a et b réelles, et c et d imaginaires conjuguées, on a encore de même une racine réelle entre a et b, et par conséquent une seconde. Admettons enfin que a et b soient aussi imaginaires conjuguées et représentons par $f(p)$ le premier membre. Pour p trés grand on aura $f(p)=\frac{a+b-c-d}{p^2}$; on trouve ensuite pour $p=\frac{a+b}{2}$, $f(p)=-\frac{a+b-c-d}{(p-c)(p-d)}$: et pour $p=\frac{c+d}{2}$, $f(p)=-\frac{a+b-c-d}{(p-a)(p-b)}$. Nous avons par conséquent encore deux racines réelles en dehors de l'intervalle compris entre $\frac{a+b}{2}$ et $\frac{c+d}{2}$.

2. At the request of the Council, Professor Schuster gave an Address on the Discharge of Electricity through Gases, with Experimental Illustrations.

Monday, 2nd June 1884.

SHERIFF FORBES IRVINE, Vice-President, in the Chair.

The Chairman announced that on June 16th, in terms of the Laws, a Ballot would take place for the following proposed Foreign Honorary Fellows :—M. Charles Hermite, Membre de l'Institut (Académie des Sciences), Paris; M. Pierre J. Van Beneden, Professeur à l'Université de Louvain.

The following Communications were read :—

1. The Enumeration, Description, and Construction of Knots, with fewer than Ten Crossings. By the Rev. T. P. Kirkman, F.R.S. Communicated by Professor Tait.

[This Paper will appear in the *Transactions.*]

2. On Knots. Part II. By Professor Tait.

[This Paper will appear in the *Transactions.*]

3. Second Note on the Remarkable Sunsets. By Mr John Aitken.

When I communicated my first note on this subject on the 21st of January last, the only definite conclusion I had then arrived at was that the very remarkable and brilliant colour effects, lately seen in the heavens at sunrise and sunset, were due to the presence of an unusual amount of dust at the time floating in our atmosphere. This atmospheric dust acts as a sifting medium, breaks up the white light into its components, and reflects all the different colours to us from different parts of the sky.

Owing to the cloudy state of our northern skies, and to the ever-varying condition of our atmosphere, it was found very difficult to follow the successive colour changes in such a way as to enable me to form anything like a satisfactory explanation of all the phenomena. Since coming, however, to the south of France, and seeing all the different sunset effects repeat themselves evening after evening in cloudless skies, I have been enabled to form a clearer idea of how the different effects are produced; and from the observations made under these more favourable conditions, I shall now attempt to give what appears to be the explanation of some of the principal phenomena of these very remarkable and brilliant sunsets.

Though it was the month of March before I saw these sunsets under the more favourable conditions, and the brilliancy of the display had very greatly diminished, yet sufficient remained to enable the different colour changes to be followed, and I was still able to detect marked differences in the brilliancy of the effects on different evenings. Briefly stated, the following is something like the order in which the different phenomena followed each other, evening after evening, in these cloudless skies, the only difference being in the brilliancy of the colours on the different evenings. During the day the sun was surrounded by an unusual amount of white light or glare. As it descended, this glare gradually increased in brilliancy and extent; but while it was still an hour from setting, no colours, save blue, were anywhere visible in the heavens, and the horizon all round was white. As the sun was

about to set, the lower part of the western horizon became tinged with yellow, which deepened to orange as the orb touched the horizon. After it had sunk below the horizon, the band of colour in the west deepened and widened. The yellow, which when first visible was close to the horizon, after a time rose higher, while the colour on the horizon gradually deepened to orange and at last to red, the upper limit of the colours at the same time rising higher and higher in the heavens. The amount to which the colour deepened, and the height to which it rose, varied from evening to evening.

For some minutes after the sun had set, nothing very remarkable appeared in the sky. Overhead it was blue, and the blue gradually changed through white to a dull reddish colour on the horizon, in the north, south, and east; in the west the blue changed by imperceptible degrees from blue into white, which melted into yellow, and the yellow in turn deepened into orange and red on the horizon. But on most evenings, within a quarter of an hour after the sun had set, a very remarkable reddish glow made its appearance high up in the western sky. When this aurora-like glow first became visible, its upper edge would be about 40° above the horizon, and extended downwards to about 15° from the horizon. The colours of this glow were quite different from any of those on the horizon. There the colours varied from yellow through orange to red; but this upper glow was a very different red from that on the horizon—perhaps crimson is the colours to which it most nearly approached. As time progressed, this glow gradually descended, till at last it merged into the sunset colours on the horizon, and the two bands melted into one. This upper glow generally took about 10 or 15 minutes, from the time it was distinctly visible, to descend and become absorbed in the horizon colours. Owing to the perspective, its upper edge seemed to descend more quickly than the lower, which made the glow appear to become narrower as it approached the horizon.

After the sun had been from 20 to 30 minutes under the horizon, nothing remarkable was visible; the upper glow having sunk into the horizon colours, the heavens had again much the same appearance they had before the upper glow began, only somewhat darker. But a few minutes after this upper glow had disappeared, a

second made its appearance. This second upper glow was not, however, confined to the west, but the whole heavens glowed with a strange reddish light, of very much the same tone of colour as the first upper glow. This second one generally seemed to attain its maximum first in the east, then all over the sky, a short time after which it died away, and the sky took up its usual night appearance. Only a very few observations of this second glow were obtained, as it was only on a few evenings that its appearance and disappearance were sufficiently distinct for the hour to be correctly noted. The time after sunset, when it appeared and disappeared, cannot therefore be given with any accuracy. I may state, however, that it appeared within a few minutes after the first upper glow had vanished, perhaps about 30 or 35 minutes after sunset, and it did not last long. It is obvious that the times here given of the first and second glows only refer to the particular cases observed. A month or two earlier, when there was more dust in the air, there is every reason for supposing that both the first and second glows would have continued much longer after sunset, as there would then be plenty of dust in the higher regions to sift the rays, also to reflect the red ones, and the sun would thus continue to shine on the dust to a later hour. It is necessary for me to state that the position from which the observations were made was such that the sun did not set on the sea, but over land, and that the land was low, and the position of observation high enough for the sun to be seen down to the true horizon.

The conclusions at which I have arrived are—1st, that the first upper glow is produced by the direct rays of the sun illuminating the particles of matter suspended in the atmosphere; and 2nd, that the brilliant western horizon light is the source of illumination of the second upper glow.

I shall now attempt to state the manner in which all the different successive colour effects are produced. The sun's rays, in passing through our atmosphere, there encounter innumerable multitudes of very small dust particles. Some of these particles are so extremely small that they can stop and scatter only the rays of small wave length; that is, those of the violet end of the spectrum. The result of this is, that the blue light is stopped and reflected in every direction, while the rays of the red end of the spectrum are

allowed to pass on. The amount to which the rays of the violet end are thrown out depends on the number of small particles encountered by them. It is generally supposed that water vapour, by absorbing the rays of the violet end of the spectrum, has a somewhat similar effect on the light passing through it. If so, the water vapour in our atmosphere will tend to deepen the red, and so intensify the effect of the dust.

The reason why a great amount of dust in our atmosphere should give such brilliant sunset effects, is that it causes a more perfect sifting action on the sun's rays in the outer strata of our atmosphere, and provides a greater amount of particles in the lower strata large enough to reflect the red rays. If there were no fine particles in the upper strata, the sunset effect would be whiter, and if there were no large particles in either upper or lower strata, then no such sunset effect would be possible. If our atmosphere were perfectly free from dust, the light would simply pass through it into space without revealing itself, *and the moment the sun dipped below the horizon total darkness would follow.* The length of our twilight, therefore, depends on the amount of dust in some form or other in our atmosphere, and the height to which the dust extends. A great amount of dust in the higher regions of our atmosphere would fully account for the greatly prolonged twilight we enjoyed while these sunset effects were at their brightest.

While the sun is still high above the horizon, its rays have to penetrate but little more than the depth of our atmosphere, and they are subjected to but a slight sifting action by the dust, the colour of the light being little changed by the small amount of blue thrown out of it, before it arrives at the surface of the earth. But as the sun approaches the horizon, its light has to pass through a rapidly increasing extent of our atmosphere, and its rays are subjected to a proportionate increase in the amount of the sifting action; so that by the time the sun is on the horizon, the sifting action is so great that all the rays of short wave length are stopped and scattered, and only those of the red end of the spectrum reach the earth; hence the illumination of any object lighted by the *direct rays alone* is yellow, orange, or red, according to the amount of sifting that has taken place.

After the sun has sunk below the horizon, the amount of air

through which the rays have to pass, before arriving at our position, still goes on increasing; and though the rays cannot now come direct to us on the surface of the earth, yet they pass through our atmosphere overhead, and illuminate any particles large enough that may be floating there. But not only do the sun's rays pass through a greater extent of our atmosphere when the sun is below the horizon, but as the rays are then at a tangent to the earth's surface, they have to pass through a greater proportion of air near the earth; and in that region there are, in addition to the large particles, more of the very fine small-wave-scattering particles, as well as more water vapour, than in the upper regions of our atmosphere. The rays, therefore, that pass have the colours of small wave length more perfectly sifted out of them, and the light tramsmitted is deeper red.

When we look towards the north, south, and east soon after sunset, we see that the sky near the horizon is of a dull reddish colour. This is due to the sun's rays being deprived of all save their red, in their passage horizontally through so much of the atmosphere, and these red rays falling on the large particles low down in the atmosphere illuminate them with red light. This red light near the horizon would be much redder if it were not for the great amount of blue light reflected to the particles from the sky overhead. As the sun sinks, but before it ceases to shine on our atmosphere, the temperature of the air begins to fall, and its cooling is accompanied by an increase in the size of the particles floating in it, due to water vapour condensing upon them. The particles to the east lose the sun first, and are thus coolest; and the rays in that direction being best sifted, the red colour is here more distinct than in the north or south.

As the sun sinks lower, the particles overhead get larger and better able to reflect the red rays; and the red colour at first visible in the east slowly rises, passes overhead, and descends in the west. We cannot, however, see it in the zenith with the unassisted eye, and it is not till it forms the first glow that it becomes visible. I have, however, been able by means of a Nicol prism to detect the presence of the red glow overhead, tracing it from its first appearance in the east, and following it in its passage to the west, long before it became visible to the unassisted eye in the western glow.

One reason why the red light is not visible overhead, is that the depth of the red reflecting stratum is not enough to stop out the great quantity of blue light coming from the sunlit air higher up; and as this blue light is complementary to the red of the afterglow, the two combine, and cause the heavens to appear whitish, both colours being destroyed; but the Nicol prism, by cutting out the polarised light, reveals the red to the eye. By examining the sky overhead with the prism, it was always possible to tell, before the first afterglow in the west began, whether it would be bright or not. If the red glow was not strong overhead when the polarised light was cut out, then the afterglow was sure to be poor. From this we see that the red seen in the east, shortly after sunset, rises and passes overhead unseen, but again becomes visible in the aurora-like glow in the west.

Another reason why we see this afterglow in the west, though we cannot see it with the unassisted eye overhead, is, that when viewing it towards the horizon, we are looking obliquely into the red stratum, and are thus receiving light from a greater depth of it than when looking upwards; we are therefore receiving a greater amount of red light, and the greater thickness also helps to block out the blue light beyond. It is very evident, however, that this does not explain some of the peculiarities in the visibility of the first glow. If the first glow, as seen in the west, is due to the sifted rays of the sun falling on particles large enough to reflect the red rays, thus producing in the atmosphere a stratum of air full of red glowing particles, then we naturally ask ourselves, Why is not this red light visible to the unassisted eye when looking towards the north, south, and east, as well as towards the west? If at sunset there is formed in the sky a red stratum, we can image it so thin as to be invisible when looked through overhead, but we should expect it to be equally brilliant in all directions, at the same elevation, or if it is more brilliant in one direction than another, we should expect the east, and not the west, to be most brilliant at sunset. Or to put this difficulty in another way. Why is it that this brilliant upper glow is visible only when viewed from a certain direction? To an observer placed to the north, south, or west of it, it is quite invisible. We know, for instance, that a short time before this upper glow was visible to us on any evening, there

was a similar glow to the south of us; and seen by observers to the south-east of us; and though we were looking into the sky where the glow was, and at the same elevation as they were, yet it was quite invisible to us.

Two explanations suggest themselves to account for this peculiarity in the glow. One supposition is, that its brilliancy is dependent in some way on the brightness of the sky behind it; the other supposition, and by far the more probable one, is, that it is due to some peculiarity in the reflecting particles. The glow being visible only on particles situated between us and the sun, would seem to indicate that the particles engaged in producing that glow are not ordinary dust particles, which absorb and radiate the light in all directions, but that this peculiar effect is produced by the regular reflection of the sun's rays. But it may be asked, Where are the necessary reflectors to come from? Now it is obvious that any small crystals floating in the air will, by the reflection from their surfaces, produce this result. All examinations of the volcanic dust lately collected from the atmosphere show that a great quantity of it is composed of small glassy crystals. An abundance of such crystals would quite account for the peculiarity in the visibility of the first glow, as these crystals would shine far more brilliantly when placed between the observer and the sun than in any other position. It is now simply a question as to whether there is a quantity of such small crystals sufficient to produce this result. The evidence seems to indicate that there is; if so, then the difficulty vanishes. Mixed with these crystals there are also large quantities of ordinary kinds of dust, and it is the light reflected by the latter which principally causes the red glow seen in the south, north, and east. Both kinds of dust are necessary fully to explain all the phenomena.

The first glow looked as if it stood vertically in the western heavens; this, however, is an effect of perspective. In reality we were looking into what was practically a horizontal layer of mote-filled air; and as the sun got lower and lower the part of this layer reflecting the red light, gradually moved westwards, which gave it the appearance of moving downwards. From the high angle at which this first glow was seen, it could not be far from us, at least when it was first visible—not more than ten or fifteen miles, perhaps much less.

On all the evenings on which this first glow was distinct, I observed a thin film of silvery cloud, if cloud it could be called, form or become visible over the western sky, just after the sun had disappeared. It was rather curious that this filmy cloud seemed to have a definite boundary underneath, its wavings or undulations being quite distinct. The peculiar silvery appearance of this filmy cloud struck me at the time, as it had a strange lustre about it; but it was not till I considered the necessity for crystalline reflectors fully to explain the peculiarities in the visibility of the first glow, that it struck me these crystals would also explain the peculiar silvery lustre of this haze or cloud. This crystalline dust would also account for the great brilliancy of the mid-day glare, accompanied as it was with comparatively little white light at a distance from the sun, and with fair transparency in the other parts of the sky, the crystals between us and the sun reflecting more light than those situated in other directions.

So far as these observations have gone, no relation has been detected between the brilliancy of these after glows and the humidity of the atmosphere, as given either by the spectroscope, or by the wet and dry bulb thermometers. The observations, so far as they go, rather indicate a dry atmosphere as favourable to brilliancy, but the observations are too few to settle the point.

We shall now suppose that our first glow has sunk down and melted into the horizon colours. The sky now has little red in it anywhere save in the glowing west. The sky is now very much the same as before the first glow began, only the light from all parts is now much less. With the assistance of these glowing colours in the west, we shall now try to explain the way in which the second glow is produced. Shortly after the first glow disappeared, it was observed that the overhead changed in appearance, the blue slowly faded and became a whitish colour. In a short time the white changed to a reddish hue, and at last the whole heavens glowed with a fine red light. Though this second glow was only now visible, it had been there for some time, but could not be seen by our unassisted eyes. If, however, we used the polariscope we could see it at any time, after the brilliancy of the first glow had gone. It was not visible to the unassisted eye, for the same reason that the first glow could not be seen overhead, on

account of the blue light from the sky overhead mixing with the red and making the sky look whitish.

Now this second glow I hope to be able to prove is not caused, like the first, by the direct rays of the sun shining on the particles floating in the air, but by the particles engaged in the first glow being now illuminated, not directly by the sun's rays, but by the glowing colours on the western horizon. The clouds, dust, and floating matter to the west of us were so brilliantly illuminated, that they in turn became a source of illumination, reflecting their reddish light in all directions, and illuminating particles suspended in the air in every direction. During last winter, when these sunset effects were at their brightest, I observed one evening, after the sun had set, this red light streaming in from the glowing west with such brilliancy as to light up the smoke of a factory chimney, making it appear of a reddish colour; while all objects in the landscape of a reddish hue shone out with a brilliancy out of all proportion to what we are accustomed to see.

This glowing light streaming in from the west falls on the particles suspended in the atmosphere, and illuminates them; and the particles on which the sun shone directly and produced the first glow, are again lit up with a reddish light. The effect of this red illumination is not at first visible, as the sun is still shining on the upper strata of the atmosphere, and the very fine dust there reflects the blue light, which mixes with the red and masks it. As the sun sinks lower, it shines on less and less of the upper air, and soon the brilliancy of the blue is only equal to that of the red; the heavens then appear whitish, and when at last the sun passes altogether out of the dusty air overhead, the red light becomes visible to the unassisted eye, and the heavens seem filled with a reddish glow.

It will be observed that the explanation here offered puts the position of the illuminated particles producing the sunset effects at a much lower elevation than has generally been supposed. It will be necessary, therefore, for me to give my reasons for supposing that the phenomena are really produced by particles floating at comparatively low elevations. This explanation supposes that only the first glow is produced by the direct rays of the sun, and the second glow by reflection, or rather radiation from the illuminated

particles near the horizion ; it is therefore necessary for me to show how this second glow is produced without the direct rays of the sun. It may be that while the second glow is visible, the sun is still shining in the atmosphere overhead, but at the time of the second glow it touches only the upper limits, and there are no particles there large enough to reflect red light. Indeed, the second glow is not visible till the rays have passed out of the air in which the particles are large enough to reflect blue light. It is clear, therefore, that the second glow cannot have its source in direct illumination.

There are different ways of satisfying ourselves that the second glow is but a reflection of the sunset colours on the horizon, by the same particles as shone by direct sunlight in the first glow. Before going further, there is a most important fact which requires attention. It is one to which we are so much accustomed that we might not give it its true value. It is, however, so important, in the study of these phenomena, that it is necessary we should constantly keep it in view. Of course, every one knows that daylight is far brighter than gaslight, but how difficult it is to realise the difference. On any ordinary day at sundown, light the gas ; it has no effect—the room is not a bit better lighted. Leave the gas lit, and as the sun sinks, note how the gas begins to light up a wider and wider area, and at last the room appears to be brilliantly illuminated by the gas alone, while outside we can still see our way about, and the last of these sunset effects are still visible. Now, try to realise this enormous scale of brilliancy we have got to deal with in daylight. We should be more sensible of the difference were it not for the curtain in front of our eyes, which nature draws closer and closer the more brilliant the light is. As only enough light is admitted to the retina to give distinct vision, and as the amount is regulated by unconscious movements, we are not so sensible as we might be of the vast scale of illumination used by nature. Keeping ever in view this vast scale of brilliancy we have to work with at sunset, it is easy to see that what is dark at one time, and under certain conditions, may really appear brilliantly illuminated a short time after under different conditions. A cloud, for instance, on a bright sky may look black, but remove the bright sky and we find the cloud is brilliantly lighted up.

When the first glow was formed, and during the time it was descending as well as when it melted into the horizon colours, the glowing west no doubt was radiating a great amount of red light in all directions, but no red glow was visible overhead, on account of the great amount of white and blue light also reflected by the sky, by which the red effect was masked; as we have seen, however, it was there all the time, but only became visible when the other light ceased to be reflected by the sky. Now, though during the second glow the sky seemed to get lit up with a red light, yet the brilliancy of its total illumination had not increased, it had rather decreased, as we can satisfy ourselves by observing that while all these changes are taking place the stars are becoming more and more numerous, showing that the daylight has been decreasing all the time.

It has already been mentioned that immediately after sundown, a thin silvery film of cloud was always seen over the western sky before the first glow became visible. What appeared to be this film has also been detected overhead with the polariscope while the sun was shining on it, and its faintly indicated outlines traced, as it shone as a red filmy cloud when the polarised light was cut off. Now, as it was observed that the second glow took place in these same filmy clouds, and that this second glow was not visible for some time after the first glow, and not till the sunshine had almost left our atmosphere, it is evident that the filmy clouds from which these glowing colours proceed are at no great elevation. Another thing which indicates that the second glow is but a reflection of the horizon colours, is that it was always possible to tell whether the second glow would be brilliant or not before it made its appearance. If the horizon colours were high up and brilliant, then there always followed a brilliant second glow; but if they were low and dark, no second glow followed. There was thus a direct relation between the brilliancy of the sunset colour and the second glow.

It may here be asked, Is the horizon glow sufficiently brilliant to light up the floating motes all over the sky, and account for the brightness of the second glow? This doubt is again suggested by something which, from its very familiarity, we have almost ceased to notice. The amount of light that streams in from the western sky after sunset is much greater than we might imagine. It is not

much noticed, because it casts but little shadow, on account of the light coming from a wide area. To satisfy ourselves, however, of the brilliancy of the western sky, compared with the north, south, or east, we have only to project, by means of a mirror, a small area of the western sky on to the eastern. Compared with the reflection of the western sky, the eastern looks black, and the projected image contrasts as strongly with the eastern sky as the sun does with the heavens at mid-day.

There is another way of studying the illuminating power of the western sky, which I had occasional opportunities of following. On some evenings there were a few small clouds floating about, just enough of them to show the successive illuminations, but not so many as to cast shadows, and interfere with each other. These test reflectors were carefully watched as the sun went down and till it was nearly dark. As the sun touched the horizon, it shone into my room, and painted an image of the window on the opposite wall in bright orange light. At the same moment it lighted up the little clouds with the same coloured light. This colour deepened on the clouds as the sun sunk below the horizon, till they glowed with a fine red light. After a little the sun had sunk so low that it ceased to shine on the clouds, their brilliancy died away, and at last they looked *black*. The sky overhead, however, still remained brilliantly illuminated. After a time a change began to appear; as the light in the sky died away the clouds lost their dark look, and gradually after a time appeared to be lighted up again; till at last their western edges *again glowed with a red light*, in general appearance very much the same as the first red illumination. This time obviously the source of the illumination was the western sky, as the clouds were much too low to catch the direct rays of the sun. The boundaries of the illuminated parts were no longer sharp, as when the sun shone on them, but hazy and indefinite on account of the light coming to them from the wide area of the western sky.

So far as I have been able to judge, the second glow which illuminated the whole heavens was produced in exactly the same way as the second illumination of the clouds as above described. On some evenings thin hazy clouds floating in the sky, a little below the haze that gave the true glow, were brilliantly illuminated with red

light, and shone more brightly than the true glow; and on some evenings, these thin clouds and the glow haze seemed to be so near the same elevation, that it was difficult to distinguish the one from the other.

It is scarcely necessary to say that the clouds, like the second glow, did not really get lit up with red light. The appearance of lighting up was not a reality, but was due to the other light dying out of the sky more quickly than the red light in the west, and the light now coming from the clouds being more brilliant than that from the sky, the clouds appeared bright on the dark sky. Some interesting colour effects were observed on the second illumination of the clouds. They were not always coloured to the same depth of red at all points where they were exposed to the western glow. The western edge of the cloud, for instance, was generally of a light red; whilst the parts which projected underneath, and were exposed to the western glow, were of a much deeper red. This was caused by the western edge of the cloud being exposed to the illumination of the white and blue sky in the west and overhead; this light with the red made the exposed edge whitish red, while the parts projecting underneath the clouds were protected from the white and blue, and exposed only to the horizon glow; they shone therefore with a redder light.

It has been said that the colour of the first glow was not the same as the sunset colours of the horizon, but was of a crimson hue. Now this is just what we might expect, because, from the lower strata in which the large particles are, red or reddish light is reflected to us, but this red light is accompanied by a certain amount of blue light from the higher strata, and the combination of a small amount of blue with the red gives a crimson tone. The second glow, for the same reason, was of a similar colour. On the horizon the red is combined with the green and yellow, causing it to appear more or less orange.

It will be interesting in the future, when all these peculiar sunsets are over, to see if we can find any of this afterglow by means of a polariscope. It is obvious that there may be a considerable amount of red afterglow in the west, without its ever being visible to us. The reason for this, as already explained, is, that a mixture of red and blue lights appear white, and as

the red glow comes to us mixed with a certain amount of blue light from the sky beyond, a certain amount of red light is masked, and it is only when the red is greater than a certain proportion that it becomes visible as red. Any amount less, only changes the blue towards white. If, however, on searching the sky overhead after sunset with the polariscope, we find the red still there, we may be sure it will be followed by a red glow in the west, though it may not be visible to our eyes.

Conclusions.

We may sum up our conclusions under the five following heads :—

1. If our atmosphere were perfectly pure, and free from suspended particles, there would be no twilight. When the sun sunk under the horizon, its rays would pass through our atmosphere into space, without revealing themselves by illuminating our sky, and the moment the sun disappeared total darkness would follow, almost as quickly as when a candle is extinguished at midnight.

2. The greater the amount of suspended particles—up to a certain quantity—there is in the atmosphere, and the greater the height to which they are diffused, the more the western sky will be illuminated at sunset, and the longer will be the twilight.

3. The greater the amount of suspended particles of extremely small size there is in the atmosphere, the more highly coloured will be the transmitted light of the sun and the reflected light of the sky.

4. The western afterglow is caused by the transmitted light being reflected to the earth by small dust crystals floating in the air.

5. When there are plenty of suspended particles in the atmosphere, the western sky at sunset becomes so brilliantly luminous that it radiates light in every direction, and illuminates the suspended particles all over the sky, causing them to shine long after the direct rays of the sun have left them.

4. Thermometer Screens. By Mr John Aitken. (Plate VI.)

Part I.

In meteorological observations the temperature of the air is of the first importance, and it is a subject to which a great deal of attention is given, thousands of temperature observations being made and recorded every day. It is therefore desirable that these observations shall be as correct as possible. At first sight nothing seems more simple than to take the temperature of the air. All that appears necessary is to hang up a correct thermometer of any construction, anywhere out of the sun, and the thermometer will then indicate the temperature of the air where the instrument is placed. We shall presently see that this is very far from being the case; and not only so, but we shall find that it is difficult to get two thermometers which will give the same readings, when hung near each other in the open air, even though they agree perfectly with each other when placed in water.

It has been the custom of most observers to place the thermometers in some kind of screen, to protect them from the sun and the rain. Many forms of screens have been devised, but Stevenson's is the one that has met with the most general approval. This screen consists of a square-shaped box, the sides of which are made of double-louvre boards. In this box the thermometers are protected from radiation, while the air can circulate freely through it. No doubt Mr Stevenson's screen is admirably adapted to our climate, where we scarcely ever have calm weather, and the temperature of the air inside the screen is generally nearly the same as that of the air outside it. My attention has, however, been lately directed to certain conditions of climate under which this screen is not suitable. In France and Italy there is frequently a succession of perfectly calm days, in which the sun shines with great brilliancy and strength. Under these circumstances I have seen the Stevenson screen baking in the sunshine, and the thermometers recording temperatures much higher than that of the air outside them. These calm, sunny days are not unknown in this country, though they may occur seldom; and it seems worth while considering whether something ought not to be done to prevent the

too high readings given on exceptional days in the screens at present in use.

To get the true temperature of the air, the simplest plan seems to be to place the thermometer in some sort of box or tube where it will be protected from radiation, and to cause a rapid current of the air to be tested to rush over it. The only difficulty in practically carrying out this method for general meteorological purposes is to get some simple means of keeping up a constant and rapid current of air. There are many ways in which this may be done, but none of them are very satisfactory. We might, for instance, by means of a pipe, connect the box containing the thermometer with a chimney, under which a fire was constantly burning; or we might keep up the draught by means of a jet of gas burning in a vertical tube placed over the thermometer box; or we might use a revolving fan and water power, or a water jet, or any other easily applied method of causing a current of air at the place where the observations are to be made. All these plans, however, require special apparatus and constant attention to see they are in working order; and though some of them might be used in certain conditions, yet none of them are suitable for general adoption. A simpler and self-acting arrangement has therefore been designed, by means of which a current of air is kept constantly flowing over the thermometer. This apparatus consists of a screen and a draught tube combined, the draught tube being heated and put into action by the sun's rays. The screen acts during ordinary dull weather when the wind is blowing, and the draught tube keeps up the air current over the thermometer when the wind falls. This draught tube is always in action when required, and most when most required, always acting more powerfully the stronger the sunshine.

Plate VI. fig. 1 shows the theoretical form of a thermometer screen made on this principle. The thermometer *t* is placed in the lower end of the vertical tube *ab*. The lower part *a* of the tube is constructed of some non-conductor, or some other arrangement is made to prevent radiant heat getting to the thermometer. The upper part *b* of the tube is made of metal, and painted black. Suppose this tube placed vertically anywhere in sunshine, the upper part of the tube will become heated, and will warm the air inside. A rapid current will

Fig. 1

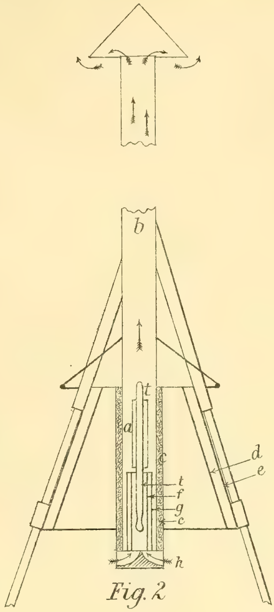


Fig. 2

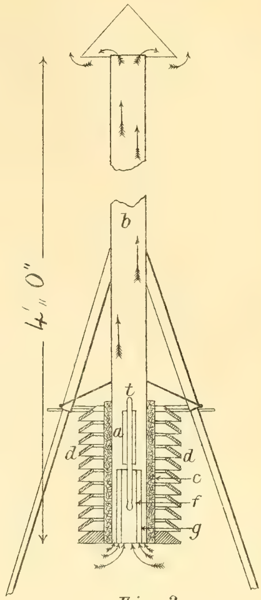


Fig. 3

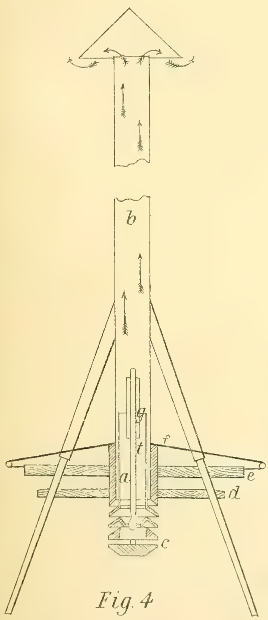


Fig. 4

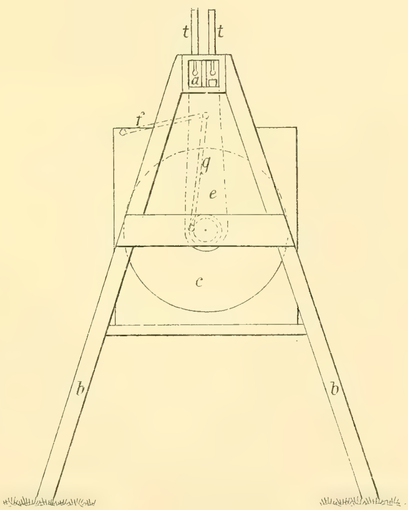


Fig. 5

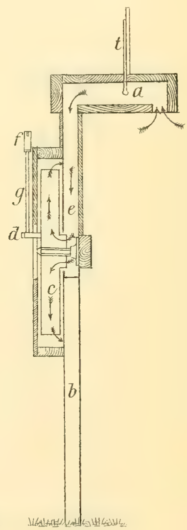


Fig. 6

1 Foot
Scale for Figˢ 1 2 3 & 4

1 Foot
Scale for Figˢ 5 & 6

thus be formed, and will keep rushing up the tube while there is any sunshine. In this way a current of air will be kept flowing past the thermometer; and the thermometer being protected from radiation, the correct temperature of the air will be obtained during calm and sunny weather.

One of the principal difficulties met with in the construction of this screen is to prevent heat getting to the thermometer through the lower part of the tube. If any heat get conducted through the walls of this tube, it will heat the air inside, and the inside surface of the tube will also radiate heat to the thermometer, and the indicated temperature will be too high.

In figs. 2, 3, and 4 are shown some of the different forms of this screen which have been made. It will be observed that they differ principally as to the manner in which the lower part of the tube is protected. In the screen represented in section in fig. 2, the thermometer *t* is placed near the bottom of the long tube *ab*, which is made of thin metal. To prevent heat getting to the thermometer, the lower part of the tube is surrounded by a second tube *c*, and the space between the tubes is filled with a non-conductor. But as all non-conductors are far from perfect, still greater protection is necessary, and the lower part of the draught tube is surrounded by two conical-shaped metal sunshades *d*, *e*. A space is left between the two shades for the free circulation of air to keep them cool. The screen is supported on three iron legs at the standard height of 4 feet from the ground.

In fig. 3 another form of construction is shown. In this instrument the lower end of the tube, as in fig. 2, is surrounded by a tube *c*, and non-conducting covering, but in place of further protecting the lower end with a shade, it is put into a circular box *d*, made of louvre boards similar to a Stevenson screen. The air which enters the draught tube of this screen comes from the lower side of the box. As this air has been in contact with the surface of the under side of the box, and may thus have got heated, there are placed inside the tube, and surrounding the thermometer bulb, two concentric tubes *f* and *g*, made of non-conducting material, to prevent the heated air from touching the thermometer. By this arrangement the air which flows over the thermometer has the true temperature, as it has never touched the surface of any solid; and as the only radiation to which

the thermometer is exposed, is that from a small surface of the ground under the open end of the tube, it has little effect, and the thermometer shows nearly the true temperature of the air. The screen shown in fig. 2 is also provided with non-conducting concentric tubes *f* and *g*, surrounding the thermometer bulb the same as in fig. 3, as these tubes prevent heat being conducted inwards towards the thermometer.

It may be thought that in these screens the thermometer is too well protected, and that it will follow too slowly the changes in the temperature of the air. The changes must no doubt be to a certain degree sluggish. This, however, does not seem practically to interfere with the readings so far as has been observed. This sluggishness will prevent sudden local gusts of hot air from affecting the readings. An addition has, however, been made to one of the screens to cause it to act more quickly while the wind is blowing. It is shown in section at *h*, at the bottom of the draught tube in fig. 2. It is simply a wind deflector, made of a circular piece of wood shaped as shown in the sketch, and having a number of thin vertical radial plates fixed on it. When the wind blows it enters the radial passages, and has its course deflected upwards and past the thermometer. In this way the wind keeps up a circulation in the draught tube while there is no sunshine. Experiments have also been made to get some satisfactory form of wind-ventilating apparatus, which could be fixed near the *top* of the draught tube, to cause a rapid upward current when the wind is blowing. The advantage of putting the wind circulator near the top of the tube, is that when placed there the air does not come into contact with any surface before it reaches the thermometer, and therefore, theoretically at least, the arrangement is more perfect than the other. The slight heating got by having it underneath the tube is found practically to be of little importance.

To combine the full advantage of wind-circulation with that of the draught tube the screen shown in fig. 4 has been devised. As before, *ab* is the draught tube. To the lower end of this tube is attached a small circular louvre box *c*, and to protect this box from the sun and rain an umbrella-shaped shade is placed over it. This shade consists of two circular discs of wood *d* and *e*, and a metal covering *f*, all fixed parallel to each other, and with air spaces

between them for the free circulation of air, to keep them cool and to prevent the heat absorbed on the top during sunshine penetrating to the thermometer. When fitted up the discs are placed horizontally, that the wind may blow freely between them from any direction. The thermometer is placed with its bulb in the louvre box, and its readings taken through an opening *g*, in the draught tube, this opening being closed with a glass plate or provided with a door. In this screen the wind blows freely over the thermometer, and when the wind falls and the sun shines the current is kept up by means of the draught tube, so that under all conditions nearly the true temperature is indicated. This screen is the last devised, and seems to possess over the other two forms the advantages of simplicity, cheapness, and convenience.

These screens are suitable only for recording maximum temperatures. For minimum temperatures the arrangement is similar to that shown in figs. 3 or 4, only inverted, the draught tube being placed underneath the thermometer. A convenient arrangement is to use an L-shaped minimum thermometer, and fix the stem into the top shade. To enable the index to be set this shade is hinged, so that it can be placed vertically to cause the index to drop.

Some of these instruments have been tested and found to work satisfactorily, but complete tests continued for some time in all weathers will be made and are required before any practical decision as to their value can be given.

Wet Bulb Observations.

In meteorology, the next most important point after the temperature, is the humidity of the air. Different methods are in use for determining this most important point, but the one most generally used is the indirect one of simultaneous readings of wet and dry bulb thermometers. These observations are generally made in some kind of screen, the wet and the dry bulbs being placed near each other. Little consideration is necessary to show us that less favourable conditions for obtaining the true condition of the air could scarcely be selected, because the amount to which the wet bulb is depressed depends, not only on the dryness of the air, but also on the rate at which the wind circulates through the screen and over the wet surface. The result of this is, that with the same degree of humidity

of the air we may have at the same temperature very different readings of the wet bulb, according to the rate at which the air may happen at the time to circulate. The quicker the circulation, up to a certain rate, the lower will be the temperature indicated. Now it is evident that if the readings are correct when taken in calm air, they must be incorrect when there is a rapid circulation; and as the rate at which the air circulates in screens is constantly varying, the observations made with the arrangements at present in use are of little value.

The reason for the difference in the readings taken under the different conditions seems to be that, when there is no circulation, the atmosphere round the wet bulb is more moist than the surrounding air, owing to the evaporation, and the wet bulb thus indicates a high humidity; but when the moist air is removed as quickly as it is formed, the temperature falls lower. In illustration of the effect of the greater or less freeness of the circulation on the readings of the wet bulb, and to show the small value of the indication of some of the instruments at present in use, I will give the readings of a combination of wet and dry bulb thermometers which is now before me. The instrument is one of a kind which is frequently used. The two thermometers are fixed to a piece of boxwood, on which the scales are marked. The bulbs of the thermometers project some distance below the edge of the scale. The thermometer and scale are carried in a metal frame which supports the water bottle for moistening the wet bulb. The observations were made in a room, to get constant conditions of temperature and moisture. The instrument was hung clear of everything, to allow of a free circulation at the back. Under these conditions the readings of the thermometers were—dry bulb 62°, wet bulb a little under 59°. The thermometers were now taken out of the frame, and hung up in the same place; the increased freedom of circulation obtained by removing the frame made the wet bulb fall to 57°. The instrument was now placed in a strong draught of air, produced by a revolving fan, when the wet bulb fell to 56°, the dry one remaining all the time at 62°. Using this instrument as was intended by the maker, it showed a humidity of about 80. When stripped of its frame and the air allowed to get freely at the wet surface, it showed a humidity of 72, and when put in a current

of air it said the humidity was only 67. From these observations we see the necessity of keeping the wet bulb at a distance from all objects which interfere with the free circulation of the air. But even with the very best form of construction, the readings taken at different times, and by different instruments, can not be compared with each other unless we can control the circulation.

For the purpose of getting the true temperature of the air with the dry bulb, the Froude, or sling thermometer has been devised, but its evident inconvenience and risk have prevented its general use. An improved form of this method of observing has been designed by Mr Edwin Clark. In his observations he uses a whirling table, to which the instrument is attached, the table with the thermometer being rotated rapidly before the readings are taken. Mr Clark has also used his whirling table for wet bulb observations. By these means a decided advance has been made, and a nearer approach to correct readings of wet and dry bulb thermometers has been obtained. The practical difficulty in working this apparatus is the impossibility of taking the reading while the air is acting on the instruments; and as the table requires to be stopped before the readings can be taken, there is time for them to change. To obviate this difficulty, I have arranged for wet and dry bulb observations a simple revolving fan arrangement for keeping up a circulation of air past the thermometers, which brings them quickly to the correct temperature, and allows the readings to be made while the air is rushing over the instruments.

This apparatus is shown in figs. 5 and 6. Fig. 5 is a back elevation, and fig. 6 a side elevation shown in section. The bulbs of the thermometers *t*, *t*, are placed in the horizontal tube *a*; a vertical division being fixed in the tube between the bulbs. The tube *a* is placed at a height of 4 feet from the ground, and is supported by the two standards *bb*, which are firmly fixed in the ground, or otherwise supported. For circulating the air a large fan is used, as it enables us to dispense with all multiplying gear, which is troublesome, and apt to get out of order when exposed to the weather. This fan is shown at *c*; it is driven by the handle *d*, which has a small radius to enable us to turn it rapidly.* The

* The handle has been coupled by means of a connecting-rod *g*, with a short lever or treadle *f*, if we may use the word, which is actuated by the hand. This

tube *a* and the fan *c* are connected by means of the pipe *e*. When the fan is revolved, a rapid current of air is drawn in through the tube *a*, and over the thermometers, which quickly acquire the correct temperatures. When the fan is turned very slowly the wet bulb falls a little below the dry bulb, and falls further and further as the velocity is increased; but this fall only goes on till a certain slow velocity is attained, after which any increase in the rate at which the fan can be driven does not alter the temperature, either of the wet or of the dry bulb, but only causes them to acquire the correct temperatures more quickly. With this apparatus we always get the same difference of temperature with the same conditions of atmosphere. It will be noticed that the upper part of the fan is cased in to prevent the air currents put in motion by it from rising and entering the suction pipe *a*, and coming into contact with the thermometers.

When this fan arrangement is put into action, the air drawn into the thermometers does not come into contact with much heated surface, and the circulation is sufficiently rapid to keep the sides of the air passage at the temperature of the air, and also quick enough to absorb any heat the thermometers may receive by radiation; it may therefore be assumed that the readings given by the dry bulb show very nearly the true temperature of the air. This apparatus has accordingly been used in preference to the Froude thermometer for testing the action of the different forms of thermometer screens, their degree of perfection being judged by the nearness with which the readings of the thermometer placed in them agreed with those given by this fan arrangement. The readings were also occasionally checked by means of the sling arrangement; which, however, is very difficult to use, especially when the sun is shining.

On the Temperature of different sized Bodies.

Before concluding this paper, I wish to record the results of some observations made to test the effect of size on the temperature of bodies placed in the open air, as these results have a direct bearing on our present subject.

Let us first consider the temperature of bodies under the most

arrangement has been found much more convenient than the handle, as an impulse can be easily given by means of it to the fan while it is in rapid motion.

simple conditions for observation. Suppose the sky overcast, with a uniform and thick covering of clouds, that a fresh breeze is blowing, and that the temperature has been constant for some time. Under these conditions, the surfaces of all bodies, large and small, in the open air, have nearly the same temperature. But now suppose the the clouds to clear away, and the sun to shine out brightly. The temperature equilibrium is soon destroyed, and the surfaces of the different bodies quickly take up different temperatures, all becoming more or less warmer than the air. The degree to which the different bodies are heated will depend on—1st, their exposure to the sun; 2nd, their exposure to the wind; 3rd, the absorbing power of their surfaces for heat; 4th, their conducting power; and 5th, their capacity for heat. But, in addition to these, I find that the size of the body, or rather the extent of its surface, has a most important influence. These remarks apply to bodies placed in shade as well as to those exposed to sunshine.

Before describing the experiments which show the effect of size on the temperature of bodies, it will be necessary for me to describe the nature of the objects surrounding the spot where these experiments were made, as the results in experiments of this kind are determined very much by the surroundings, every position giving a different result according to the objects to which it is exposed. The view from the position of these experiments is bounded on the south and west by trees at a considerable distance, on the east by shrubs close at hand, and backed by a wall which extends southwards, and closes in the view to the south-east. One half of the north is bounded by a wall at a distance of 6 feet, and the other half by trees at a distance, while the ground is covered with grass in nearly every direction. This site was selected on account of its being sheltered from the wind, and otherwise suited for the experiments.

When studying the action of the draught tube thermometer screen, the experiments were begun by erecting, in the position above described, a horizontal sunshade made of wood, 3 feet long by 2 feet broad. This shade was erected at a height of about 5 feet from the ground. In the sunshade was made a round opening, into which fitted a tall metal tube. This tube projected 1 foot downwards into the shade and 2 feet upwards into sunshine. Experi-

ments were now made by testing the readings of a thermometer when placed in different positions. The results with which we are at present concerned were got when the thermometer bulb was pushed up inside the tube, and when it was pulled down clear of it. When the bulb was pulled down and clear of the tube, it always showed about a degree lower than when in the tube. Now, why was this? The thermometer and the tube were both subjected to the same conditions, and we might have expected that they would have the same temperature, that the thermometer would read the same inside the tube as outside, or we might have expected it to be cooler inside the tube, as it would there have the advantage of the upward current; yet it showed a higher temperature inside than outside. I now stopped the upward current in the tube to see the effect on the thermometer. Whenever the current was stopped, the temperature began to rise till the thermometer was more than 2° higher than when placed outside the tube.

It was thought that the high temperature inside might be partly due to the heat radiated from the hot upper part of the tube. The apparatus was therefore taken within doors, to get a constant temperature, and the draught tube heated by means of a gas flame. No increase of temperature was, however, observed when the upper part of the tube was heated. We may therefore conclude that but little heat is radiated downwards, or at least that all the heat that is radiated to the thermometer is easily carried away by the upward current of air. Another possible explanation is, the difference in the absorbing powers of the surface of the tube and of the thermometer bulb. As the tube, however, was polished tin, their absorbing powers would not differ greatly. Neither of these explanations, therefore, seem satisfactory. The other explanation which suggested itself was that the difference in temperature was due to the difference in size of the two bodies, the thermometer bulb being about $\frac{1}{4}$ of an inch in diameter, while the tube was nearly 3 inches.

When we consider the conditions under which the thermometer and the tube were placed, we can easily see that the comparative size of these objects would have a most important influence in determining their temperatures. When the sun is shining, all objects exposed to its rays get heated, and they in turn become sources of

radiation, and radiate heat to all surfaces in every direction within their view. All surfaces, therefore, though shaded from the sun, are receiving a great amount of radiant heat; and if this heat was not carried away by the air, the surfaces in shade would acquire nearly the same temperature as those in sunshine. But the supply of heat comes in slowly from the sunlit surfaces, and the passing air carries it away nearly as quickly as it is received. We see from this that the temperature of bodies, even in the shade, is greatly determined by the rate at which this radiant heat is carried away. Now, very little consideration is necessary to show us that the air will carry away the heat much more quickly from a small than from a large surface. When a current of air comes into contact with a hot surface, the air where it first touches the surface is rapidly heated, and a film or layer of hot air is formed near that surface. Now, if the body is small, this hot layer is at once swept away, and gives place to another cold layer, which in turn abstracts more heat; whereas in a large body, the hot film or layer formed where the current first touches the body keeps near the surface in its passage over it, and forms, as it were, a hot protecting coat to all parts of the surface at a small distance to the leeward of the point where the current first touched it. No doubt this hot layer of air will thicken as it passes over a large surface, but the rate at which it thickens is very slow after it has passed over a very small distance. This I have observed in my late experiments on dust. The effects due to the heat in the air in front of a hot flat vertical surface are almost all accomplished at the lower edge of the plate, where contact is first made, the upper part of the plate producing but a slight increase in the effect. The result of the air acting in this way is, that a large body parts with its heat to the passing air at a much slower rate per unit of area than a small body does; and as both are receiving heat at the same rate, the temperature of a small body is lower than that of a large one. The protection of large bodies will be far from being so perfect when the currents are rapid and the air ceases to move in stream lines.

Experiments were made to see if this reasoning was correct, to determine whether large bodies were really hotter than small ones, and if so, to what extent. For this purpose I prepared three tin boxes, all 8 inches long, but of different

diameters, being $\frac{1}{2}$ inch, 2 inches, and 4 inches respectively. These boxes were provided with an opening in the centre of one end, for the purpose of introducing a thermometer to determine their temperatures. Before being used they were painted black, to get a good and a uniform condition of all the absorbing surfaces. After a thermometer was fitted into each box, they were all hung up under the horizontal shade, and perfectly protected from the direct rays of the sun. Alongside of the boxes was hung a thermometer with a clean bulb, also a thermometer having the bulb blackened with the same paint as used for the boxes. After they had hung for some time, no two of the boxes were found to have the same temperature. The larger the box the higher was its temperature. The difference between the temperatures, as might be expected, was not always the same, because on no two days is the amount of radiant heat the same, nor is the rate of circulation of the air the same. The following table shows the readings taken at two different times on the same day:—

Clean Bulb.	Blackened Bulb $\frac{1}{4}''$ diameter.	Box $\frac{1}{2}''$ diameter.	Box 2″ diameter.	Box 4″ diameter.
67°	68°	69°·5	71°·3	74°·1
71°	72°	74°·2	76°	79°

These readings, of course, only show the comparative temperatures at the particular place on the day the observations were made. Some days the difference was less, but in spring weather, when the sun is hot and the air cold, greater differences may be looked for.

The boxes with their thermometers were then hung up under the horizontal sunshade in an open field, clear of all buildings, and surrounded by trees at some distance. The amount to which the different boxes were heated was found to be almost the same as in the more confined place, where the tests were first made; showing that the amount of heating is not much influenced by the nature of the surrounding objects.

The above readings were shade temperatures; the boxes were now

hung up in sunshine, to see the effect of size on objects exposed to the direct rays of the sun. The following table shows the result:—

Clean Bulb.	Blackened Bulb $\frac{1}{4}''$ diameter.	Box $\frac{1}{2}''$ diameter.	Box 2″ diameter.	Box 4″ diameter.
78°	80½°	84°	89°·5	95°

Objection might be taken to the manner in which the above experiment was made. It might be asked, for instance, Was not part of the difference of temperature due to the heat received on the side of the box next the sun being quickly conducted to the shade side, in the small boxes, and carried away by the wind, while in the large boxes the heat could only be slowly conveyed to the shade side by the hot air in the box? To check these results, I filled the large box with a liquid, using turpentine, on account of its small specific heat. Placing this box in sunshine, and alongside of it the half-inch box, in which was fixed a maximum registering thermometer, it was found that the large box attained a temperature of 96°, while the thermometer in small one indicated a maximum of 85°, thus confirming the result of the previous experiment.

We might look on these boxes with attached thermometers simply as thermometers with very large bulbs. We see from this that the indications of correct thermometers may vary when hung in certain positions, owing to a difference in the size of their bulbs. No doubt these are very extreme sizes, still I find that the size of the bulbs of the thermometers in general use does affect their indications. Selecting two thermometers, one with a large and one with a small bulb, I hung them up beside each other under the shade, and found that the one with the smallest bulb indicated a temperature about half a degree lower than the large one. I may say that the precaution was taken of checking the readings of these thermometers in water at the same temperature as the air. It is possible that a difference in the thickness of the walls of the bulbs may have caused the large thermometer to absorb more heat than the other, but this can scarcely account for the whole difference.

Not only will the size of the bulbs affect the indications in the open air, but the manner in which the thermometer is mounted will

have an important influence. Anything which prevents the free circulation of the air near a bulb, or which comes in contact with the air before it reaches the thermometer, will cause it to read too high. The system of sinking half of the bulb into a wooden frame cannot but interfere with the correctness of the indications, save when the thermometer is perfectly protected from radiation, and even then it makes the instrument sluggish. All thermometers not protected by proper screens, such as those used in gardens, and for other rough purposes, ought to have the bulb perfectly exposed to the air, and as far away from all surfaces as possible.

To illustrate the effect of size and radiation, I may mention that when I found that small bodies were cooler and nearer the temperature of the air than large ones, I repeated my experiment with the horizontal shade and vertical draught tube, but in place of enclosing the thermometer bulb in a three-inch tube, a very small one was employed, just large enough to allow a current of air to flow freely between it and the bulb. The result, however, was that the upward current did not quite compensate for the larger size of even this small tube, and the thermometer was never quite so low in the tube as out of it, and exposed to the wind blowing at the time. No doubt, in a calm day this arrangement would have prevented any great rise in the temperature, and the arrangement would have been better than some screens or than no screen.

These experiments, while they indicate certain errors in the construction of thermometers, suggest some possible advances and improvements. We have seen that the temperature of a body exposed to radiation in the open air is colder the smaller it is. The meaning of which is that the smaller a body is, the less effect radiant heat has on it, and the nearer its temperature is to that of the air. Carrying out this line of thought, we see that if we could construct thermometers sufficiently small in the bulb, they would indicate nearly the true temperature of the air, and if small enough they would indicate nearly the true temperature even in the sunshine. A thermometer made of a fine wire, for instance, would be well enough protected if simply screened from the direct rays of the sun. At present I am attempting to get a mercury thermometer made with a very fine bulb, which it is hoped will give nearly the true tempera-

ture of the air when placed under a sunshade such as that shown in fig. 4, but without the louvre box. I regret that the time taken in getting a satisfactory instrument of this kind made prevents me from being able to say how near the indications of such an instrument will approach the true temperature of the air.

These experiments have also suggested the construction of a cheap and simple radiation thermometer, which has been made in the following way :—An ordinary thermometer, or a registering one by preference, is let into the surface of a thick piece of wood. The best size of this casing has not been determined, but it ought to be at least a foot square, or, better still, large enough to encase the whole stem of the thermometer. The thermometer is let in to such a depth that the bulb is level with the surface of the wood. Cement is then put in to fill up all inequalities and restore perfect smoothness to the board. The surface is afterwards blackened. It may be mentioned that, in order to make the instrument act quickly, a large cavity is cut in the wood, into which the bulb of the thermometer is placed, and the cavity is packed with cotton-wool, and covered over with a thin layer of the cement. There have only been two opportunities for making observations with this instrument. On one afternoon it was placed in sunshine, and alongside was hung a thermometer with a blackened bulb, but exposed to the air. The blackened bulb only rose to a temperature of 78°, while the one fitted into surface of the wood rose to 105°.

This effect of the size of the surface of a body in determining the amount of the cooling effect of the air will, I hope, help to explain some difficulties. And one cannot help asking here, whether we have not in this a suggestion as to the explanation of why it is that dust in the sun's rays, focussed by a powerful lens, escapes being burned. It does seem strange to any one accustomed to use a "burning glass" to light cigarette or pipe, that the organic dust passes through the focus of his lens without being affected; but the moment the focus falls on the solid tobacco, it at once responds with a cloud of smoke. Now why is this? Does not the difficulty of heating small bodies by radiant heat suggest the answer? It is true the conditions are not alike. The small bodies we have been experimenting with are comparatively large; and further, a

necessary condition is that they are fixed, and that the air moves over them, whereas the dust particles move with the air. But may not a precisely similar cooling effect be brought about in another way? In the case of a very small object, like a dust particle, a molecule of air, which has touched it and got heated, passes into the widening space outside, and scarcely never returns to the dust particle; so that every air molecule that touches the particle is cold, and the heat received by the particle is not conserved by the heated molecules keeping near it and protecting it from contact with the cold ones. In this way the molecular movements accomplish for the dust what the mass movements do for fixed bodies.

These experiments also suggest some thoughts regarding the thermal experiences of different forms of life. The tiny insect, as it sports in the sunshine, is the one above all others which is generally supposed to have the greatest enjoyment in the warmth of the sun's rays. From what we have seen, we now however know, that it is the one above all others which has the least reason for gratitude, as it can scarcely receive any heat from the sun. Let the sun shine as brightly as it may, it can scarcely warm to a perceptible degree the tiny limbs of these fluttering insects; and if it will enjoy the sun's heat, it must descend to earth. And what a change does it meet with there when it lights on branch or stem of tree! In a moment it passes into an atmosphere twenty or thirty degrees warmer than the sunlit air in which it delights. On the other hand, this immunity from the heating effect of the sun makes life possible to these insects under a sunshine that drives the larger animals to seek the shade.

Part II.

(Added 23rd August 1884.)

Since the first part of this paper was written, there has been some weather suitable for testing the efficiency of the thermometer screens under trying conditions. From the beginning of the month till the 22nd there were a number of warm, bright, and nearly calm days. Under these conditions it is well known that it is difficult to get the true temperature of the air; advantage was therefore taken of

these exceptional conditions for making a number of test observations with the screens.

For a standard of comparison, the fan apparatus already described was used. The first thing to be done was to test the action and efficiency of the draught produced by this fan. In this apparatus the vacuum produced is less than $\frac{1}{4}$ of an inch of water, and the current consequently is not very strong. I therefore first compared its action with that of a more powerful instrument, the fan of which is driven by multiplying gear, and which easily gives a vacuum of 1 inch of water, and draws a perfect hurricane of air over the thermometer. Working these two instruments alongside of each other in the open air on a bright day, there was not found to be any difference in the readings of their respective thermometers; showing that for all practical purposes the draught in the simple apparatus gave as correct results as the powerful draught of the more complicated fan. The only advantage of the powerful apparatus was, that it brought the thermometer more quickly than the other to the temperature of the air.

The readings of the fan apparatus were now compared with those given by the sling thermometer. The result was, that whenever there was any sunshine, the fan thermometer read lower by one degree than the sling, and if the sun was bright the difference was more than one degree. I shall presently show why these two methods of testing the temperature of the air should give different results, and why the sling should read higher than the fan arrangement; also why the lower temperature given by the fan is nearer the true temperature of the air than that given by the other.

In the following experiments with the screens the fan apparatus has been used as a standard, as it is, I think, more correct than the sling method, and also because it is much more easily worked. Assuming then the fan apparatus as our standard instrument, it was fitted up alongside of the screens on a lawn, in a position well protected from any little wind that might be blowing, so as to get the most trying conditions possible for the screens acting correctly. The amount of wind during most of the experiments was very small, and generally from the east. At times there was scarcely a breath of air, and during the calm periods frequent readings were taken. In conducting the experiments, the fan was kept in constant action,

and whenever the temperature was at all steady, readings were taken of the thermometers in the different screens.

The result of these tests has been satisfactory. The thermometer in none of the screens rose much above the standard, even during the most trying conditions of the experiments. The thermometer in screen fig. 3, under many conditions read almost the same as the standard; but on one or two trying occasions, when the wind died away and the sun shone brightly, the error was quite decided, and amounted to an average of a little over half a degree. From my notes on these occasions, I see that it read sometimes exactly the same as the standard, but at other times it was one degree too high; generally, however, the difference was not so great, and gave an average of 0°·6. It may be objected that we cannot average errors of this kind, because the maximum error may be the true error of the instrument, as the maximum temperature to be registered might happen just when the error was greatest. From the manner in which the experiments were made, it is, however, I think the average, and not the maximum that is the true error of the screen. The occasions on which the error was greatest was when the temperature was changing. The readings were taken while the temperature was falling; and as the fan thermometer follows the changes more quickly than the screen, it had fallen more than half a degree before almost any change was effected in the screen thermometer; so that when the readings were taken the screen thermometer was still recording the higher temperature to which it was previously exposed. These tests do not show that the maximum of screen was ever one degree higher than the maximum of the standard. A more correct method of testing would have been to employ maximum registering thermometers, and to take the maximum temperature indicated during a certain time. This method was intended to have been followed, and special registering thermometers were being prepared, but they were not ready in time for the experiments, which had to be made before the hot weather was over for the season.

The screen shown in fig. 4 has almost exactly the same error as screen fig. 3. Though its indications are nearly as true as those of the other, yet it does not seem so susceptible of improvement. It may be possible to reduce its error by changing the form of the screen at the bottom of the draught tube. It can, however, scarcely

be expected to act as correctly as the other, because the louvre boards of the screen become heated by radiation, and the air passing over them gets warmed before arriving at the thermometer.

In the construction of screens it is necessary to shade the thermometer as much as possible from all radiation. It ought not to *see* anything out of its screen. A small amount of exposure even to the grass underneath shows its effect in an increase of temperature. This could be observed when testing the screen fig. 4. If the bottom was taken out of the box, to allow of a freer circulation, the temperature always rose a little. On the other hand, if the louvre box was made too close by the addition to it of complicated louvre boards, the flow of the air was retarded, more heated surface was given to warm the air before it arrived at the thermometer, and in this case also the thermometer read too high. The arrangement shown in the sketch is the one which as yet has been found to give the best results. The thermometer is so protected that no radiation from objects outside can fall directly on it, while the free circulation of the air is but little checked. Perhaps an improved form of box for this screen might be made of double louvre boards, but as this would increase the outside diameter of the box, and consequently the amount of surface over which the air has to pass; it would also greatly reduce the velocity of the air when no wind was blowing, and only the draught tube acting; it is therefore very doubtful whether any advantage would be obtained.

From the experiments on the temperature of large and small bodies already detailed, we have seen that large bodies become more highly heated than small ones, when exposed either to the direct rays of the sun, or only to diffused radiation. From this we get some guidance for the construction of thermometer screens. As large bodies are less cooled by air passing over them than small ones, it follows that the louvre boards in the thermometer box ought to be as large as possible, because the air in passing over large louvres will carry less heat into the box than if it passed over small ones. The large size of the louvres will also prevent heat being conducted to the inside of the box. Again, if we wish to lessen the radiation from any particular area, we must reduce all objects exposed in that direction to as small dimensions as possible, and coat them with some substance which is a good absorber of radiant heat. Blackened

wire cloth, for instance, freely exposed to the air, will get but little heated even in sunshine, and will neither radiate nor reflect much heat.

Attempts have been made to improve the working of the screen (fig. 3) by cutting off all radiation from the ground. First, a small non-conducting screen was fixed horizontally under the tube, but leaving plenty of space for the air to enter freely; but no decided advantage was obtained. Then a small screen was placed in the tube, just under the thermometer bulb, to check the radiant heat falling on it, but no reduction in temperature was effected. No great advantage can be got from placing a small screen under the bulb. If the effect of the upward radiation from the ground is to be entirely checked, it must be cut off from the inside surface of the tube, as well as from the bulb; as I find that, to get rid of the last fraction of a degree above the temperature of the air, it is of far more importance to check radiation, than to increase the current past the bulb; as a very small amount of radiation is equal to a strong current of air, and the changes of temperature in a thermometer are far more quickly accomplished by radiation than by contact with the air. These considerations show us that the tube surrounding the bulb, in addition to being a non-conductor, ought to be made of some substance that has small capacity for heat, so that its temperature may change quickly with that of the air; because the changes in the thermometer are caused more by the exchange of heat with the surface of the tube than by contact with the air passing over it. In these instruments the inner concentric tubes are made of blotting paper kept in shape by thin metal tubes. Hair felt, if it could be got of suitable shape, might be better than paper.

The screen constructed according to the plan shown in fig. 2 does not give quite such good results as the one made as shown in fig. 3. In the former screen the draught tube is of a less diameter, and the lower part is less protected by non-conducting coats and air passages than the latter. This suggests that the fraction of a degree too high, given by the thermometer in screen fig. 3, is partly caused by heat conducted through the lower end of the tube, and radiated across the air passages. This supposition has been confirmed by an examination of the air passages by means of a thermometer. The temperature of passage next the

centre tube was found to be generally about half a degree higher than in the centre tube, while the outer passage was often more than a degree higher, showing that the lower end of the tube is not properly protected. Another screen is therefore being prepared, with a more perfect screen protection, a larger draught tube, and more concentric non-conducting tubes and air passages, and it is hoped this new screen will have a less error. It will be remembered that the fan thermometer is, under the conditions during the experiments, always about one degree below the sling thermometer, so that screen fig. 3 is nearly half a degree nearer the truth than the sling.

It is only within the last few days that I have been in possession of a Stevenson screen, and been able to make comparative trials with it. During these tests its action was compared with the fan apparatus, and readings were taken at the same time of the thermometers in the draught tube screens. These latter, as already stated, had an average error of about 0°·6 too high. The smallest error recorded in more than thirty readings of the thermometer in the Stevenson screen was 1°·3, and it only fell to that on two occasions. The excess error was generally more than 2°, and was as high as 2·8 on two occasions. The morning on which the trials were made was certainly a trying one, but was not so bad as it might have been, for the Stevenson screen. The sun was very strong, and there was but little air moving; the direction of the wind, however, was favourable, being from the north-east, so that the air entering the screen passed over the cold louvre boards and not over the sun-heated ones. If the wind had been southerly, the error would have been greater, as the entering air would have been heated in its passage over the hot louvres. These tests were made on an exceptional day. On most days, when there is wind, the screen gives a much nearer approach to the truth than it did on that occasion. By a slight addition to this screen, I was able, when the error was high, greatly to reduce it. On those days on which the wind blew from a northerly direction, and the air entering the screen came in from the cool side of the box, I found the high temperature given by the thermometer was due to radiant heat entering the open bottom of the box. Either a solid or a louvred bottom has been found greatly to improve the correctness of this screen, but whether the solid or the louvred bottom is the best has not yet been deter-

mined, and whether this addition will work equally well in all weathers or not remains to be seen.

Radiation Thermometers.

Some observations have been made with the radiation thermometer already described. In addition to this instrument, another has been prepared. In this second instrument a small circular chamber is made in the centre of the black surface, and covered with thin glass let in level with that surface. The thermometer with its bulb blackened is exposed in the middle of this chamber. This instrument always reads higher than the other one in which the bulb forms part of the surface. For this reason, it is perhaps not so satisfactory as the other, as it possesses something of the so-called "bottling up" powers of the black bulb *in vacuo.* These radiation thermometers were generally exposed in sunshine while the trials with the screens were going on. Their indications, of course, varied from hour to hour and from day to day. The highest temperatures observed were on the afternoon of the 7th August, when the thermometer fixed in the black surface rose to a temperature of 144°, and the one in small chamber in the black surface indicated a temperature of 154°. On the 8th, and on some other days, the temperature was nearly as high. When the observations were made, the instruments were generally placed near the ground with the black surface perpendicular to the sun's rays, and freely exposed to any wind that might be blowing. On dull and sunless days these thermometers often read 10° or 15° higher than the temperature of the air.

Thermometers with Protected Bulbs.

A short time ago, I received one of the thermometers specially constructed for the experiments with small bulbs, to which reference has been made in the former part of this paper. The directions for the construction of this thermometer were to make the bulb as long as might be necessary to give the desired capacity, but its diameter as small as possible. The bulb of the instrument sent is, however, not by any means so small as desired, nor so small as it might easily have been made. Owing, however, to an unex-

pected change in the manner of working, this defect has not been of importance, and the instrument has been found to be very serviceable. The bulb is very long, being 55 mm. or more than 2 inches, and has a diameter at the top of 3 mm. and of 2 mm. at the bottom. It is graduated from 0° to 100° Fahr., and has an expansion at the top of the tube to prevent bursting when heated over 100°. The large capacity of the bulb has given a long and easily read scale, there being almost 2 mm. between each degree.

It may be remembered that this thermometer was constructed for the purpose of following up a line of investigation suggested by the experiments on the temperature of large and small bodies exposed to radiation. It had been found that the smaller a body was, the nearer its temperature was to that of the air surrounding it, because it was more quickly deprived, by the passing air, of the heat received by radiation from surrounding objects; and there seemed reason for supposing that if the bulb of a thermometer was small enough radiation would not heat it to a perceptible degree. This thermometer was therefore constructed with the intention of seeing how nearly a thermometer with a very small bulb would indicate the true temperature of the air.

Owing to an unexpected change in the development of this investigation, but few trials were made with this instrument as received from the maker. A few tests were, however, made. In these experiments the thermometer was placed under a horizontal sunshade, which protected it from all sunshine, and from nearly the whole of the sky radiation. The day on which the experiments were made was bright and warm, with a slight air from the east. The radiation thermometer already referred to showed a temperature of 140° in the sun. Under these conditions, the new thermometer always read just about a degree higher than the fan thermometer, and was generally more than half a degree lower than another thermometer with ordinary sized bulb placed alongside of it. It is, therefore, evident that this instrument, though better than an ordinary one, cannot be relied on to give the true temperature of the air when shaded in the manner described; as it would read correctly only on dull days, and be a degree more or less too high according to the brightness of the day. If the bulb of this thermometer had been made smaller, as ordered, it is possible the

error might have been less. Dr Lenz* has recently described an application of the telephone to the measurement of temperatures at a distance. Dr Lenz connects the observer with the distant station by means of a thermo-electric combination of wires, into the circuit of which he introduces a silent interrupter and a telephone. If the temperature of the junction at the distant station is not the same as that of the junction near the observer, a sound is heard in the telephones, which ceases when the observer has made the temperature of his junction the same as that of the distant one. This arrangement suggests a method of getting the true temperature of the air, by making the thermo-electric junction or junctions of as fine wire as possible, and exposing them freely to the air under shade at the distant station. In this way we might get as small a sensitive surface as it is possible to construct.

On reconsidering the whole matter at this point, it soon became evident that it is hopeless to expect any thermometer of ordinary construction, however small the bulb, to give the true temperature of the air while it is exposed to radiation. When we consider what is taking place it is easy to see why this must be so. When radiant heat falls on the bulb of a thermometer, the heat is absorbed not only at the surface of the bulb, but all through the thickness of the glass, and at the surface of the mercury. The inside of the bulb therefore gets heated, and this heat must be conducted outwards through the glass before it can be carried away by the air. The consequence is, the inside of the bulb is hotter than the outside, and the thermometer while exposed to radiation must always read too high, however strong the current of air may be to which it is exposed. As the absorbed heat requires to be conducted to the outside, the inside of the thermometer must always be considerably hotter than the air, so long as the radiation temperature is higher than the temperature of the air.

The natural sequence to these thoughts was—cover the bulb with something through which radiant heat cannot penetrate; and as it would be necessary to use some substance having a small absorbing power for radiant heat, silver naturally suggested itself as the most suitable material for the purpose. I accordingly coated the bulb and part of the stem of the fine-bulbed thermometer with silver

* *Nature*, vol. xxx. p. 345.

deposited on it, from a solution of the nitrate. By this simple process I had now acquired an extremely interesting and curious instrument. Its powers of repelling radiant heat, if we may use the expression, are very remarkable.

My first experiments with this instrument were made in the beginning of this month. I first wished to get the heating effect of the sun's rays on this silvered thermometer in calm air; the experiments were therefore made in a room, and only enough of the window opened to allow the sun to shine in on the thermometer, which was placed with its bulb in sunshine. Alongside the silvered thermometer was hung an ordinary thermometer, and readings were taken from time to time of the temperature of the room and of the sun-warmed thermometers. In these tests the silvered thermometer never rose more than one degree above the temperature of the room, and was often only half a degree, and sometimes less, while the other thermometer rose from 4 to $4\frac{1}{2}$ degrees above the temperature of the room. In these experiments it was found extremely difficult to get the true temperature of the room with an ordinary thermometer, so much depended on where the thermometer was placed, and the amount of radiation that reached it, but the result given is as correct as I have been able to make it. Another difficulty in making these experiments is the extreme sensitiveness of the fine-bulbed thermometer, it is so constantly rising and falling nearly a degree in little more than a minute. To give an idea of the difficulty of getting the temperature of the room where the experiments were made, I may mention the following, as it at the same time shows how much the indications of ordinary thermometers are affected by radiation. At one stage in the experiments the thermometer employed for giving the temperature of the room was hung alongside the other thermometers, but provided with a shade which protected it from all direct sunshine. When in this position it was in the same air as the silvered thermometer, yet it always read higher, sometimes by nearly one degree; that is, the ordinary thermometer was more heated by the radiant heat from the carpet, and other objects in the room on which the sun was shining, than the silvered bulb was by the direct rays of the sun added to the radiation from surrounding objects.

The next tests with this instrument were made outside under the

ordinary conditions for testing the temperature of the air. The thermometer was placed under a sunshade, similar to that shown in fig. 4, but without louvre box at bottom, or draught tube at top. The stem of the thermometer passed through the sunshade, the silvered bulb was freely exposed under the shade, while the scale projected through the top of the shade for convenience in reading. The bulb was thus protected only from the direct rays of the sun, and from the greater part of the sky radiation. The fan apparatus was used as a standard as in the test with the screens. It must be confessed that the result surprised me not a little. That the readings of the silvered thermometer would be nearly as low as those of the fan thermometer, I quite expected; but that they should be almost always lower, was somewhat astonishing. There can be no doubt but that it does read lower, but how much it is very difficult to say. I have made many and continuous observations with it in different conditions of weather, but it always read lower than the thermometer in fan draught, when the silver coating was at all in good order, the weather bright, and the slightest air of wind moving. I have watched the two thermometers for hours under trying conditions from calmness and brilliancy of sun, and yet the result was always the same. The difficulty of saying how much lower the exposed silvered thermometer was than the fan thermometer, arises from the extreme sensitiveness of the fine-bulbed silvered thermometer to rapid changes of temperature. Sometimes it rises higher than the other by a fraction of a degree, but only for a very short time, and at other times it falls much lower, the changes taking place quickly. The thermometer in the fan, on the other hand, follows these changes more slowly, and never goes to the same extremes. The quickness of this instrument is most interesting, and reveals to us a most curious fluctuating state of the temperature of our atmosphere. The mercury in it is in a constant state of ebb and flow. That these ups and downs really indicate changes in the temperature of the air, or rather differences in temperature in different parts of the passing air, and are not due either to changes in radiation or to variations in the cooling effect of the wind, is I think indicated by the fact, that it was always possible, by watching the silvered thermometer, to tell whether the thermometer in the fan draught was going to rise or to fall, as all its indications

were predicted by the silvered thermometer. The changes in the fan thermometer are slow compared with the other, owing to the shape of the bulb, and to time being required to alter the temperature of the air passages, which radiate heat to the thermometer. So nearly as I was able to judge from observations made when the temperature was nearly steady, the average reading of the silvered bulb was about a quarter of a degree below the fan readings. It might sometimes be less when the air was calm.

The silvered thermometer scarcely rose one degree above the standard when hung in sunshine during a fine calm day, while the radiation thermometer similarly exposed showed a temperature of 131°, or 65° above the temperature of the air.

As a great deal of radiant heat is absorbed by the glass of the bulb of an ordinary thermometer, not only at the surface, but all through the body of the glass, it seems probable that part of the lower temperature indicated by the small bulbed thermometers is probably due to this cause; the small bulbs having a less thickness of glass than the large ones, as bulbs with thin walls will absorb less radiant heat than those with thick ones, and will also conduct the absorbed heat more quickly outwards to be carried away by the air.

I have frequently referred to the constant fluctuations in the temperature of our atmosphere. Now, to prevent any mistake in this matter, it will be as well for me to state more clearly the amount of these fluctuations. With a thermometer having a large bulb, these changes are little noticed; but after one becomes accustomed to the careful reading of thermometers with medium-sized bulbs, they become very evident. In the fan apparatus the changes on certain days would amount to half a degree more or less almost every minute, and in the fine-bulbed thermometer they often amounted to a degree or more in the same time. These changes take place whether the wind circulation is strong or slight.

It may be as well for us to consider here why the thermometer in the fan draught should read higher than the silvered thermometer. No doubt the silvered bulb will be a little higher than the temperature of the air, but why should the fan give a higher reading still? So far as I understand it, part of this higher reading given by the fan apparatus is due to heat conducted inwards

through the indraught tube, and radiated to the thermometer; and part is due to the air which enters the tube having first touched the outside of the apparatus, and in this way got heated before arriving at the thermometer; while the silvered thermometer is less heated by diffused radiation when exposed freely to the air than the thermometer in the fan apparatus.

All these experiments have been made with the silver coating deposited on the bulb by chemical means. A comparison of many different experiments with different thermometers shows a variation in the protecting power of the different coverings due to their greater or less thickness, and also to their greater or less perfection, and freeness from scratches which remove the silver from the glass. In some of the experiments the thermometers had two and three coatings of silver put on them, by placing them in successive baths; the surfaces of the bulbs being simply washed when taken out of one bath and placed immediately in the next. When taken from the final bath, some of the bulbs looked dull and dusty, but acted quite well, while others were improved by polishing with rouge.

These chemically deposited silver coverings being rather delicate for practical purposes, the next thing to be done was to get a silver sheath prepared for the thermometer bulb. This sheath was made of thin sheet silver and fitted easily over the bulb, and it also covered part of the stem. The silver coating being dissolved off the thermometer bulb, the silver sheath was polished, and fitted on, and the thermometer tested as before with the fan apparatus. The result in this case was not so good as with the chemically deposited silver. The readings of the thermometer now almost exactly corresponded with those of the fan thermometer; that is, the silver sheath reduced the readings 1° lower than the clean glass, but gave about 0°·25 higher than the deposited silver. These higher readings suggested that this sheath was not made of pure silver. On inquiry, I found this to be the case; so another sheath was prepared, and special precautions taken to have the silver as pure as possible.

This second sheath was tried on the morning of the 18th, when there was a bright sun and almost no wind. As in the previous experiments, the thermometer was simply placed under a horizontal

sunshade. The sheath was found to act almost as well as the chemically deposited silver, but not quite, its readings being generally about 0°·2 below the fan thermometer. As silver has a tendency to tarnish, it was thought as well to try the efficiency of gold as a protector. Gold is not quite so well suited for the purpose, as it absorbs more radiant heat than silver; while silver only absorbs 3 per cent., gold absorbs 5 per cent. The first sheath which was prepared for the thermometer, and which was made of impure silver, was gilt with gold, and tested under the same conditions as the pure silver sheath. It was found to be not nearly so efficient a protector as the silver, its readings being generally about 0°·2 above the fan thermometer, or nearly 0°·4 higher than the pure silver. The gold gilt sheath, after being very much finger-marked, made the thermometer read nearly 0°·5 above fan, or about half a degree better than clean glass. As to whether gold or silver is the best for practical purposes can be determined only by continued use. Gold has certain advantages, as it will probably keep its protecting powers longer than silver; and where frequent cleaning is inconvenient, gold may be the most suitable; but when great accuracy is aimed at, silver must be employed.

The action of these silver-coated thermometers is most curious and interesting. They never agree with any other thermometers when hung alongside of each other in a room into which the sun is shining, or in which the gas is lighted; and even after the windows are closed, and shutters shut, or the gas put out, it is long before they agree with the others. Like captious critics, they always underestimate the radiations emanating from surrounding bodies, and manage to keep themselves cool amidst the heat exchanges taking place on every side. If we examine the readings of an ordinary thermometer, it is influenced by our presence; and if long in making our observation, the heat radiated from our body may cause the thermometer to indicate a temperature half a degree too high; but these silvered thermometers are almost indifferent to our presence, while they are sensitive to the temperature of the air.

Sling Thermometers.

The sling or "Froude" method of taking observations has generally been accepted as the most accurate way of determining

the true temperature of the air. The result of the preceding experiments seems to indicate that observations taken in this way may not be correct, owing to a fundamental error in the construction of the apparatus. We have seen that radiant heat is absorbed in the thickness of the walls of the bulb, and at the surface of the mercury as well as at the surface of the bulb, and this internally absorbed heat must be conducted outwards to the surface before it can be carried away by the air through which the thermometer is rushing in its circular flight. There will evidently therefore be a heating effect due to radiation, which it is impossible to keep down by the cooling effect of the air, and the only question is, what is the amount of this heating? Following up the same line of experiment as was previously employed to prevent the internal absorption of heat by the bulb, and to reduce the surface absorption to a minimum, two similar thermometers were selected, the bulb of one being coated with silver and the other kept clean. These thermometers were firmly tied together and slung with as great rapidity as was thought safe. The readings of these thermometers were then compared with each other, and with the fan arrangement. The result of a number of trials was, that when slung in sunshine the silvered bulb always read at least one degree lower than the clean bulb. Compared with the thermometer in the fan draught, the silvered thermometer was a small fraction of a degree higher, while the clean bulb was higher by more than 1°. These figures of course varied with the heat of the sunshine.

These experiments show us that the ordinary sling thermometer in a bright day is more than 1° too high; probably it is $1\frac{1}{2}$° to 2° too high in bright weather, as we must remember that the fan indications are not quite down to the true temperature of the air. These experiments also show us that the silvered sling is nearer the truth by at least 1° than the thermometers generally used. Other experiments made at the same time show that slinging the silvered thermometer has no advantage over simply placing it in shade, even if there is only a slight air of wind moving; this proves that it takes all the cooling effect of rushing through the air to counteract the heating effect of the sun's rays. Instead of slinging the two thermometers, they were hung up under a sunshade on a day when a little wind was blowing; the readings then obtained agreed very

nearly with those got by slinging. From other experiments made in different states of the weather, it is found that there is not much advantage got by slinging the thermometers, either silvered or clean, in sunshine, unless there is extremely little wind at the time. Almost exactly the same degree of truth can be got by simply shading the thermometer from direct sunshine, and from the sky radiation.

Another experiment to test the heating effect of the sun on the sling thermometer was made in the following way:—An ordinary thermometer was placed near the mouth of the suction tube of the powerful fan apparatus. First the thermometer was carefully shaded from all radiation. The thermometer under these conditions agreed with the thermometer in the other fan apparatus. The open mouth of the tube was now directed towards the sky, so as to allow part of the sky radiation to fall on the bulb. The effect was to cause this thermometer to read a little higher than the other, and when the tube was directed so as to allow the sun's rays to fall on the bulb, its indications were more than a degree above the other fan thermometer. This shows us that even a powerful draught of air will not compensate for the exposure of the thermometer to the sun, and confirms the conclusion we have come to that the readings of the ordinary sling thermometer are at least one degree too high.

Temperature Observations without Screens.

We have seen that, in taking the temperature of the air, there are different methods of operating. First, we may surround the thermometer with a screen to catch all radiant heat, and prevent it falling on the thermometer, as is done in the Stevenson screen and in the one shown in fig. 4. The disadvantage of this method of working is that the air in passing over the louvre boards gets heated before entering the screen, and coming into contact with the thermometer; and though in the screen fig. 4 the louvre boards are not heated by direct sunshine, and the circulation is kept up independent of the wind, still it can scarcely be expected to give correct readings, but must always be a little too high. A second method of operating is to cut off all radiation as far as possible, isolate the thermometer from all conducted heat, and bring to it air which has never been in contact with any solid, and has not therefore got heated. This method has been employed in constructing

the screens shown in figs. 2 and 3. A third method is to reduce the absorbing power of the thermometer bulb, and expose it freely to the air, so that it may absorb as little radiant heat as possible, and make the bulb small, so that the heat received may be carried away by the air as quickly as possible. This plan has been adopted in the thermometer with silvered bulb.

In all these different methods of working, the enemy we have been contending with is radiation, and though we may have succeeded in greatly reducing its influence, yet it must be admitted that it has still some power. Seeing then we have been unable thoroughly to vanquish our enemy, perhaps the wisest course now open to us is to see if we cannot make an ally of it, and enlist it in our service.

We know that large bodies are more highly heated by radiation than small ones; we also know that different coloured bodies are heated to different degrees by radiant heat. Here then we have the foundation of a method of estimating the temperature of the air, by observing the difference in temperature, either of different sized or of different coloured bodies. For the obvious reason that the changes of temperature in different sized bodies do not take place at the same time, they evidently are not suitable for our purpose; but, on the other hand, different coloured bodies are. If we can find out the relation between the absorbing powers of two substances, then we can, by simply coating the bulbs of two thermometers with these and noting their different temperatures, tell what the temperature of the air is. Suppose, for instance, one substance heated the bulb of the thermometer twice as much above the temperature of the air as the other, then we should only require to take the readings of the two thermometers, and subtract the difference between them from the lowest, to get the true temperature of the air during the day, and add the difference to the highest, to get the temperature at night.

In practically carrying out this plan and selecting the substances most suitable for coating the bulb, one great object evidently is to get substances which will not change, and which can be easily kept in order. Now in these respects no substance is more suitable than glass, and one thermometer ought therefore to be kept with its bulb clean. As for the other bulb, something is required

which will heat it twice as much as clean glass when exposed to radiation. Any other relation in the heating effect would do, but twice is the simplest to work with. Black paint is too powerful; but I find that coating one half of the bulb with black paint or black varnish works very satisfactorily. The advantage of black varnish is that it is fairly permanent, adheres firmly to glass, and can be easily renewed if required. The black surface ought not to be put all on the same side of the bulb, but should be in at least two sections, opposite each other, as the radiation from all directions may not be equal.

I have found the working of these differential radiation thermometers very satisfactory, and it is easily done. Suppose, for instance, the blackened bulb reads 69° and the clean one 68°, then the temperature 67° is easily found. With practice the eye becomes quickly accustomed to the working of the instruments, and easily gets the true temperature mentally, even when dealing with fractions. These remarks are true only if the thermometers are correctly graduated. If the thermometers are not correct, most people will require to note down the readings, and make the necessary corrections, before adding or subtracting the difference. One point of importance is, to be very particular about the reading of the lowest or clean bulb temperature, in the day observations, as any error in it is doubled in the final result. For night observations, it is the error in the maximum reading that is doubled, and in this case also it is the readings in the clean bulb that have to be most carefully attended to.

For experimenting with these differential readings, I selected two thermometers which were nearly correct at the part of their scale corresponding to the temperature at the time of the observations. These differential radiation thermometers were placed under the same sunshade as the thermometer with the silvered bulb. This enabled the comparisons to be quickly made, and prevented the constantly changing temperature of the air from interfering with the results. By watching the differential thermometers till they were nearly steady, then rapidly subtracting the difference in their readings from the lowest or clean bulb, the result generally agreed perfectly with the readings of the silvered thermometer, and never differed by more than a small fraction of a degree.

In working with these differential thermometers, it is not necessary to screen them from the diffused radiation. If they are simply shaded from the sun, it is enough. The principal point to be attended to is, that they are placed where there is as free a circulation of air as possible, and not near any surface on which the air might be heated before coming into contact with them. When permanently fitted up, the screen required for them should be all above the bulbs, and may be of the simplest description sufficient to protect them from the weather. Two pieces of wood fixed parallel to each other, and with an air space between them, to prevent heat descending to the under side of the screen, is quite sufficient, and only requires to be securely fixed in a horizontal position. The thermometers are placed with their bulbs projecting a short distance below the screen, and the scale above it. One of the principal things to be aimed at is to secure a free circulation of air, and to prevent heated air coming to the thermometers, the screen having nothing to do with the diffused radiation, as it is welcomed and allowed for by the instruments.

This differential arrangement may be used for maximum and minimum registering thermometers. So far as the experiments go, they seem to give truer readings than most forms of screens; and as the air can circulate freely over the bulbs without being heated or cooled on louvre boards, the thermometers follow the changes of temperature quickly. Further, as the maximum error of a clean glass bulbed thermometer under those simple screens is scarcely ever 2°, and is more generally only about 1°, the amount of correction necessary is not great, and can be easily made.

Night Temperatures.

But little has been done in observations of night temperatures; no trials of the minimum screen have as yet been made. A few trials, however, with the silvered bulb were made on the 19th of the month, when the sky was clear and air calm and chilly. The experiments were conducted in the following manner:—The two thermometers used in the sling experiments, the one with bulb silvered and the other clean, were tied firmly together, and prepared for sling observations. The thermometers were first slung, and their readings taken; then they were hung up freely exposed to the

sky, and clear of all surfaces, and so that air could circulate freely over them. After time was allowed for them to acquire their respective temperatures, their readings were again taken. They were then slung and read, and so on, a number of readings being taken when slung, and when hung up. The result was that the thermometers read almost alike when slung, but the clean bulb always fell more than one degree and sometimes nearly two degrees when hung in the calm air. This fall was always nearly regained when slung; whereas slinging did not produce any decided effect on the silvered bulb, the effect being so small as to be lost in the changes in the temperature of the air. These experiments show us that the silvered bulb is as suitable for night as for day observations, and that practically it takes up the temperature of the air. radiation having but a small effect on it. The differential radiation bulbs also seem well suited for night observations; but the bulbs require to be coated in a different manner from those used in day experiments, as the *quality* of the heat is then different.

Conclusion.

For travellers, these differential radiation and silver coated thermometers seem to possess special advantages, as they enable the observer to get nearly correct readings without screens, because he can be nearly indifferent to all save direct sunshine, and will be able with confidence to expose his thermometers anywhere, in shade, where there is a free circulation of air.

One result of these experiments is to show us that, even when working with our most accurate methods of observation, we have been regularly overestimating the temperature of our bright days by about one or two degrees, and in some climates this overestimate may be even greater. In recording future observations with the sling thermometer, it will be necessary to say whether the temperatures have been taken with clean or with silvered bulb thermometers, in order that the necessary corrections may be made.

It is no very pleasant conclusion to an investigation such as this, to find that it ends in taking a degree or so off the average maximum of our summer temperature. Had it been in my power, it would have been far more pleasant to add to it a degree or two. We may, however, console ourselves with the idea that we have,

so to speak, been simply taking stock of the amount of the world's capital invested in the heat of our atmosphere, and our investigation shows us that we have been overestimating this quantity, and that the produce of the world is obtained by a less expenditure than we supposed.

Monday, 16th June 1884.

EDWARD SANG, LL.D., Vice-President, in the Chair.

The following Communications were read :—

1. Abstract of Paper on Micrometrical Measures of Gaseous Spectra. By C. Piazzi Smyth.

[Printed in full, with Plates, in the *Transactions.*]

Ever since the Royal Society, Edinburgh, was pleased to accept my paper in 1880, on the general appearance of Gaseous Spectra, as seen on a very small scale; but complete on that scale from end to end of the visible spectrum,—I have been desirous of presenting them with some very highly-dispersed views of the more intricate portions of those spectra.

An example in that direction was finely set by MM. Angstrom and Thalen in the *Upsala Transactions* in 1875. But though their work was splendid for its day, it is not enough to satisfy the demands of theory now.

These demands, too, are so terribly exacting, that I have had to labour for several years at continual cumulative improvements of my private spectroscope, before it attained power and precision enough for the present work. This, however, is the comparative condition lately attained.

My spectroscope of 1880 had a dispersion of 3°, with a magnifying power on the telescope of 10 times; say for the simple eye = 30° from A to H.

The Upsala instrument had a dispersion of 24°, with a magnifying power of about the same; say = 600° from A to H.

But my present spectroscope has 60° of dispersion; a magnifying power on the telescope rising to 36; with a further mechanical magnifying of 5 times. Equal altogether to 9000° from A to H;

or to the simple dispersive action, as viewed by the unassisted eye, of no less than 1800 prisms of dense flint glass.

The result of such an immense prismatic power on a bright continuous kind of light, such as that of incandescent carbon, is to produce a coloured spectrum strip, virtually 120 feet long, or stretching all round the meeting hall of R. S. Ed. And the regions or places of its several successive colours will be the places also of any lines of the same colours which we may meet with in the bright line spectra we are about to observe.

CH, or Carbo-Hydrogen, in Flame.

Beginning with the compound gas CH, in its Coal-gas form, and burning in a blow-pipe in the open air—very nearly as described to this Society by Professor Swan in 1856—the new instrument confirms all his findings, with the addition of further details.

There are, for example, 5 bands, widely separated from each other—the orange, the citron, the green, the blue, and the violet. Each of these bands is intense towards the red, vanishingly faint on the violet, side. Each of the first four bands, too, is made up of certain strong lines and much interstitial and following haze.

But the new instrument further shows that each of those strong lines is double, and the haze is entirely resolvable into a far minuter class of lines or linelets; excessively close on the red side, but continually widening towards the violet.

With each of those bands I measured between 80 and 90 of such linelets; and only stopped then, not because any definite termination of them was reached, but because they had then become too broad, faint, and hazy to justify micrometrical measure being expended upon them.

A grand constant was however thus obtained, of a useful character, for reference in certain disputed questions in spectroscopy. And if for sharpness of definition and precision of detail it left much to be desired, I endeavoured to supply that by subsequently employing as the illuminant, not flame of any kind, but the well-known electric spark of the induction coil. Even this, however, may be sometimes insufficient for definition purposes, unless appropriately used; for

The *simple induction spark*, tried on chloride of sodium vapour in the open air, though less hazy than flame, was of a crackly, uncertain

nature, touching its power and manner of showing the two D lines of the solar spectrum.

The *condensed induction spark* filled all the field of view with continuous fervid glow, and quaking air-bands almost fearful to behold.

But a *vacuum tube* of Hydrogen, with a trace of sodium chloride, showed of the latter only the two D lines, each of them intensely bright, exactly defined, without any stray light; and, in short, exactly as they should be to serve any case of Micrometical measure.

CH again, but now in Vacuum Tubes.

Trying the vacuum tube method, therefore, on Coal-gas, the first tube, though bright enough, was yet a failure; for it was not bright with the coal-gas spectrum, but with a variety of impurities and decomposed materials. After this, however, had been got over to a considerable extent by increasing the density of the gas put into these so-called vacuum tubes from 0·1″ to 2·5 inches of Barometric pressure, the Citron and the Green bands of CH were produced in a condition for examination. They ran quite parallel with their blow-pipe congeners, but were far more refined: the linelets being often like exquisitely thin spider lines, in place of broad hazy threads. But they did not last; for day after day they grew fainter, more and more of them became first double, then treble, and then faded away, lines of pure Hydrogen coming in their stead.

The leading Orange band of the CH spectrum was particularly difficult to observe, on account of the intrusion of these H lines. But after having appealed from Coal-gas to Olefiant gas, and having increased the pressure of that up to 4 Mercurial Inches, the cynosure was obtained at last, resulting in what may be termed a perfect view of the beginning of the CH spectrum, and of that alone.

There, for instance, was the Orange band, with its leading lines brilliant, and its linelets clear and distinct, though continually widening in distance apart, but in unbroken series not only to the usual place of vanishing but right up to the strong beginning of the Citron band.

The Citron band's linelets similarly continued in exquisite perfection of gradation right up to the Green band. And the Green band's linelets continued without a break, or an interference, or

foreign intrusion of any kind, right up to the Blue band,—save, that shortly before that notable Spectrum milestone was reached, a faint, but extensive grey cloud was passed!

What could that mean? It proved to be the then broadened or hazy condition of the usually sharp line known as Glaucous Hydrogen. Minute by minute that cloud brightened and narrowed, while the CH linelets continually paled; and after an hour's sparking the H, of the once CH, had come out in lines everywhere; while its C was deposited as a brown glazing on the inside of the tube; and my beautiful example of a perfect CH spectrum was gone for ever.

But if we bear in mind how H behaved with regard to C therein, and compare that presently with the actions of O (Oxygen) in the same relation, the experience will be well worth the price paid for it. For the chemical interpretation of those spectra is still under perfectly radical disputation.

The CO Spectrum.

A CO spectrum is easily procured, and with the smallest charge of either Carbonic Oxide or Carbonic Acid. Moreover, it remains and even improves by use.

At first sight, the CO spectrum is superficially much like the CH, inasmuch as it is a spectrum of coloured bands, intense towards the red, vanishing towards the violet. But there are more of them, and they have no leading lines in them like the CH, being composed of linelets only.

Moreover, every such linelet is of a different constitution; for while those of CH are weak and semi-transparent like spider-lines, the CO are hard, sharp, and densely metallic.

In fact, in place of both of them being spectra of one and the same simple element C (Carbon) as usually held in London, I may rather say that we are in presence, before them, of two most opposite principles of the physical world. The H, in CH, always trying to free itself from contaminations of every earthy matter; but the O, in CO, taking hold of everything near it, and of C most particularly. Whence it comes that CH tubes generally end in showing only H; whereas some other tubes, begun with a different gas, end in showing nothing but CO.

Or if that is a petty scale on which to allude to the actions of

universal Nature, let us say with the American Astronomers, that if this earth were touched by the Sun, and so sublimated by its terrific heat, that in a moment nothing of terrestrial substance would be left, except molecules and atoms vibrating in the intense light and temperature,—the H lines would be seen above, like a Solar red prominence, while the CO would be increasing its domain below.

But would such a reproduction of Nebular haze bring back the Chaos of the Greeks, or a reign of law and numerical order?

Let the last Plate of this paper (see *Trans.* vol. xxxii. part ii.), and its view of the beginning of the Green band of CO now declare; for what was mere haze to smaller instruments is here proved by higher dispersion, conjoined with improved definition, to be a most curious and exact mathematical arrangement of lines, without one missing one.

Of Elemental Gases.

HYDROGEN.

But if H, in CH, makes the carbon element behave so very differently to what it does when in the power of O, as CO,—how do H and O behave when single and separate? Let us begin with H.

Tubes of H vacuum are very bright to the naked eye, and to the spectroscope are multi-linear all the way along from Ultra Red to Violet. I have measured the places of 1625 of them. They form generally an open kind of groupings, occasionally exhibiting exquisite specimens of close sharp doubles and trebles, but never enlisted into a rigid band system. It is rather a most free and aerial kind of atom dance from one end of the spectrum to the other in a pure H tube.

OXYGEN.

Oxygen, on the other hand, is a poor lighter up; and was declared by the British Association's Committee's Report in 1880 to have only 4 lines in its spectrum, and those very faint.

Those 4 so-called lines I have identified readily enough by place, and they are the brightest of the faint appearances in that spectrum, but there are many others to be noted. Three also of the first 4 are triples of a very peculiar and uniform formation. They join too with three others which I have since discovered, in making a

long connected system of rigidly similar triplets, extending all across the spectrum from Scarlet to Glaucous. Besides which, the whole spectrum commences with a notable Ultra Red line which outflanks, or is further towards the invisible red than any line in any other gas.

NITROGEN.

Nitrogen in vacuum tubes must come in here, for though I may have some suspicions that it will be found eventually not to be a simple gas, it is practically so to all present science.

Nitrogen's tube spectrum then begins only a very little short of the Ultra Red line of O; and rapidly rises to remarkable and almost continual brilliance in five long and successive groupings of 10 or 11 bands each.

This, in a general way, has long been known; but what I have now to add, besides the discovery of the earliest or most Ultra Red group, is the resolution of these bands into lines; into hundreds and thousands of lines finer, sharper, and set more closely together than the lines of any other gas.

A good idea is given of them in the Plates of Orange and Green "N," now presented to the Society, and like all the other plates are reduced copies of my original measures and drawings, lately executed for me by Mr T. Heath, the first Assistant in the Observatory, and who has remarkable skill and understanding for such work.

Of Elemental Gases Generally.

If an elemented gas, such as that of Carbon, or of Iron, can only exist as a permanent gas at the temperature of the condensed electric spark, it can pretty evidently have for us only the one gaseous spectrum due to that temperature; for man knows no other higher stage.

But if it be the case of a gas permanent at all temperatures from the lowest to the highest, it may have besides the condensed spark spectrum, the simple electric spark spectrum, and also what we may call the cold spark, or the auroral spectrum.

Each of these three spectra too, of one element, must, under appropriate circumstances, have its reversal or double; as from bright lines in a dark field to dark lines in a bright field.

There are thus 6 conditions under which the spectrum of a permanent elementary gas may be viewed; but seldom more than two or three or these have been observed by any one.

Thus with Oxygen, the most advanced of all the gases,—

(1) Its condensed-spark bright-line spectrum has been much written on by Angstrom, Thalen, Kirchoff, Bunsen, Hoggins; and the dark reversal of some of these lines is now being worked at by Professors Liveing and Dewar.

(2) Its simple-spark bright-line spectrum is what has been described in this paper; but the dark reversal of these lines, either single or triple, has not yet been accomplished by any one.

(3) Finally its Auroral, or cold-spark spectrum, though never yet seen in the bright form, has been long witnessed unconsciously in the dark variety by every one who has ever noted the huge telluric black lines in the Solar Spectrum known as A, B, and Alpha; the identification of the first two of these lines with Oxygen having been recently established by M. Egoroff of St Petersburg, by looking through a tube of condensed Oxygen 66 feet long, at a bright continuous spectrum of the lime light; and the structural identity of the 3rd, with the 1st and 2nd, having been since then most ingeniously worked out by M. Cornu in Paris.

OF HYDROGEN.

(1) At condensed-spark temperature, and also in the Sun, H's three grand lines are well known, both in the bright and the dark conditions.

(2) Its simple-spark multilinear spectrum, in the bright state, has been described here; but the reversal is unknown.

(3) And of its cold-spark, or Auroral spectrum, nothing I believe is known either in the bright or dark variety.

AND OF NITROGEN.

(1) At condensed-spark temperature, the report is the same as for Oxygen.

(2) At simple-spark temperature, the bright line form has been described in the preceding pages; but its reversal is unknown.

(3) And of its cold-spark, or Auroral spectrum, nothing I believe has yet been positively ascertained either for bright or dark lines.

2. On the Computation of Recurring Functions, by the Aid of Chain-Fractions. By Edward Sang, LL.D.

3. On Extensions of Euclid I. 47. By A. H. Anglin, Esq.

In Euclid I. 47, it is proved that if regular tetragons be described on the sides of a right-angled triangle, that described on the hypotenuse is equal to the sum of those on the sides containing the right angle. This proposition, as is shown in Euclid VI. 31, is only a particular case of a more general one; and the object of this Paper is to establish the corresponding result in the case of regular trigons, pentagons, hexagons, and generally regular figures of any number of sides, and finally, in the case of any similar rectilineal figures, *without the use of ratio and proportion.*

1. The case of regular trigons or equilateral triangles admits of an easy and independent proof, somewhat like that of squares as given in Euclid; but the following general proposition will enable us to establish the case of regular polygons of any number of sides, including of course these two particular cases:—*If isosceles triangles of the same vertical angle be described on the sides of a right-angled triangle as bases, that one on the hypotenuse is equal to the sum of the other two.* (*A.*)

Let G, H, P (fig. 1) be the vertices of isosceles triangles of the same vertical angle described on the sides of the right-angled triangle CAB; then if D, E, F be the middle points of the sides, GD and PE will meet at F, since the line drawn through the middle point of the side of a triangle parallel to the base bisects the other side. Through H draw HK parallel to GFD, or perpendicular to CB. Join FK and GK, and produce them to meet BG and AB in M and L respectively. Then shall GKL be perpendicular to AB.

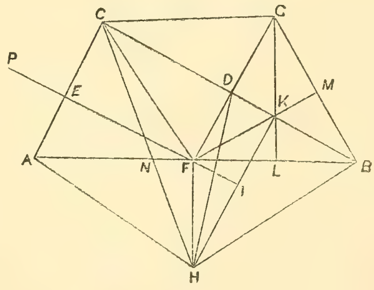


Fig. 1.

For a circle may be described about the figure HFKB; therefore the angle KHB is equal to the angle KFB. But the angle HBK is equal to the angle FBM, since the isosceles triangles are equiangular; therefore the remaining angle FMB is equal to the remaining angle HKB, and is a right angle. Thus K is the orthocentre of the triangle GFB, and the line GKL is perpendicular to FB.

Hence the figure FGKH is a parallelogram, and FG = KH, and therefore the triangle GFB is equal to the triangle BHD, since the rectangle whose sides are FG and DB is equal to the rectangle whose sides are HK and DB.

Thus the whole figure GCFB is equal to the whole triangle HCB; that is, denoting the isosceles triangles by A, B, C respectively,

$$A + \mathrm{CFB} = \mathrm{HNB} + \mathrm{CNF} + \mathrm{CFB},$$

$$\text{or} \quad A = \mathrm{HNB} + \mathrm{CNF}.$$

$$\text{Similarly} \quad B + \mathrm{CFA} = \mathrm{HNA} + \mathrm{CNA},$$

$$\text{or} \quad B + \mathrm{CNF} = \mathrm{HNA}.$$

$$\text{Thus} \quad A + B = C.$$

Now let regular polygons of the same number of sides be described on the sides of the right-angled triangle, and suppose R, S, T to be the centres of the polygons. By joining R, S, T to the angular points of the respective figures of which they are centres, the polygons will be divided into the same number of isosceles triangles which are equal to one another in each polygon. But, since these triangles have the same vertical angle, by what precedes

$$\Delta\mathrm{TAB} = \Delta\mathrm{RBC} + \Delta\mathrm{SCA}.$$

Hence the regular polygon described on AB is equal to the sum of the regular polygons of same number of sides described on BC and CA. (*B.*)

2. Since the sides of the triangle GDK or of HFI are equal to FH, DG and PE respectively, it follows that

$$\mathrm{HF}^2 = \mathrm{DG}^2 + \mathrm{PE}^2,$$

$$\text{But} \quad \mathrm{FB}^2 = \mathrm{DB}^2 + \mathrm{CE}^2,$$

$$\text{Therefore} \quad \mathrm{HB}^2 = \mathrm{BG}^2 + \mathrm{PC}^2,$$

and thus the equal sides of the isosceles triangles are also the sides of a right-angled triangle. Now draw a line from B at right angles to CB, and let it meet CG produced in J; then the triangle BGJ is isosceles, BG being equal to GJ, and is equal to the triangle GCB. The same being true in the case of corresponding triangles BHO and CPQ described on the other side, it follows that

$$\Delta BHO = \Delta BGJ + \Delta CPQ.$$

But HB, BG, and CP are the sides of a right-angled triangle; and this triangle being equiangular to the triangle ABC, the triangle BGJ is *any* isosceles triangle described on BG. Hence the proposition follows in the case of equiangular isosceles triangles, *one of their equal sides being respectively a side of the right-angled triangle.* (*C.*)

The case of similar segments of circles described on the sides may be deduced either by the application of result (*A*) or of (*C*). The latter may be employed by inscribing in the circles, of which the described segments are parts, regular polygons of the same number of sides, and joining their centres to the angular points of the polygons which are external to the sides of the triangle. These joining lines being the sides of a right-angled triangle, it may be shown by (*C*) that the figure external to AB is equal to the sum of the corresponding figures for BC and CA, and therefore, in the limit, the proposition follows in the case of the segments.

It may, however, be more simply shown by the application of (*A*) directly. Let AB (fig. 2) be the hypotenuse of the right-angled triangle ABC, and ADEB any segment of a circle described on it. If D be the middle point of the arc, the triangle ADB = sum of the corresponding triangles by (*A*). Again, if E be the middle point of arc DEB, since DB and the corresponding lines are sides of a right-angled triangle, the triangle DEB = sum of corresponding triangles. Proceeding in like manner with the arcs DE and EB, it follows finally that the segment DEB = sum of corresponding segments. The same being true of the segment AFD, therefore the whole segment AFDEB = sum of similar segments on CA and BC. (*D.*)

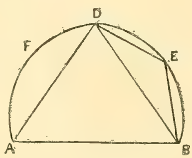


Fig. 2.

3. The cases of certain *irregular* figures, in addition to those of isosceles triangles, are then deduced.

If in fig. 1 a line be drawn from B at right angles to CB, and meet CG produced in J, the triangle CBJ is double of the triangle CBG. Hence the proposition follows in the case of equiangular *right-angled* triangles, one of the sides containing the right angle being a side of the given triangle; and hence also in the case of *similar rectangles* described on the sides. (*E*.)

Again, it follows from (*C*), since the perpendicular from the vertex of an isosceles triangle on the base bisects the triangle, that the proposition is true in the case of equiangular right-angled triangles, the *hypotenuses* being respectively a side of the given triangle; and also, by doubling the triangles in result (*C*), it follows in the case of *rhombuses* of the same angle, described on the sides. (*F*.)

By combining these results we may show the proposition true in the case of *any* similar triangles described on the sides.

For, since CJ, the hypotenuse of the triangle CBJ, is double of CG, and since CG, and corresponding lines HB, CP, have been shown to be the sides of a right-angled triangle equiangular to ABC, so also will CJ and its corresponding lines be the sides of a similar right-angled triangle.

Again, the corresponding sides in the class of right-angled triangle in (*F*) are also the sides of a right-angled triangle. For, if GU be drawn at right angles to BJ, GUB is such a triangle by what precedes. But GU is half of CB. Thus GU and corresponding lines are sides of a triangle similar to ABC.

Now, let AB (fig. 3) be the hypotenuse of the given triangle ABC, and let the triangle ADB, right-angled at D, be described upon it. By result (*F*) the triangle ADB = sum of corresponding triangles on other sides of ABC. Produce D, and draw any line AE to meet it at E. Then, since AD and corresponding lines are the sides of a right-angled triangle, we have, by (*E*), the triangle ADE = sum of corresponding triangles. Thus the whole triangle ABE is equal to the

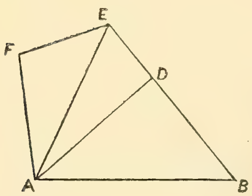
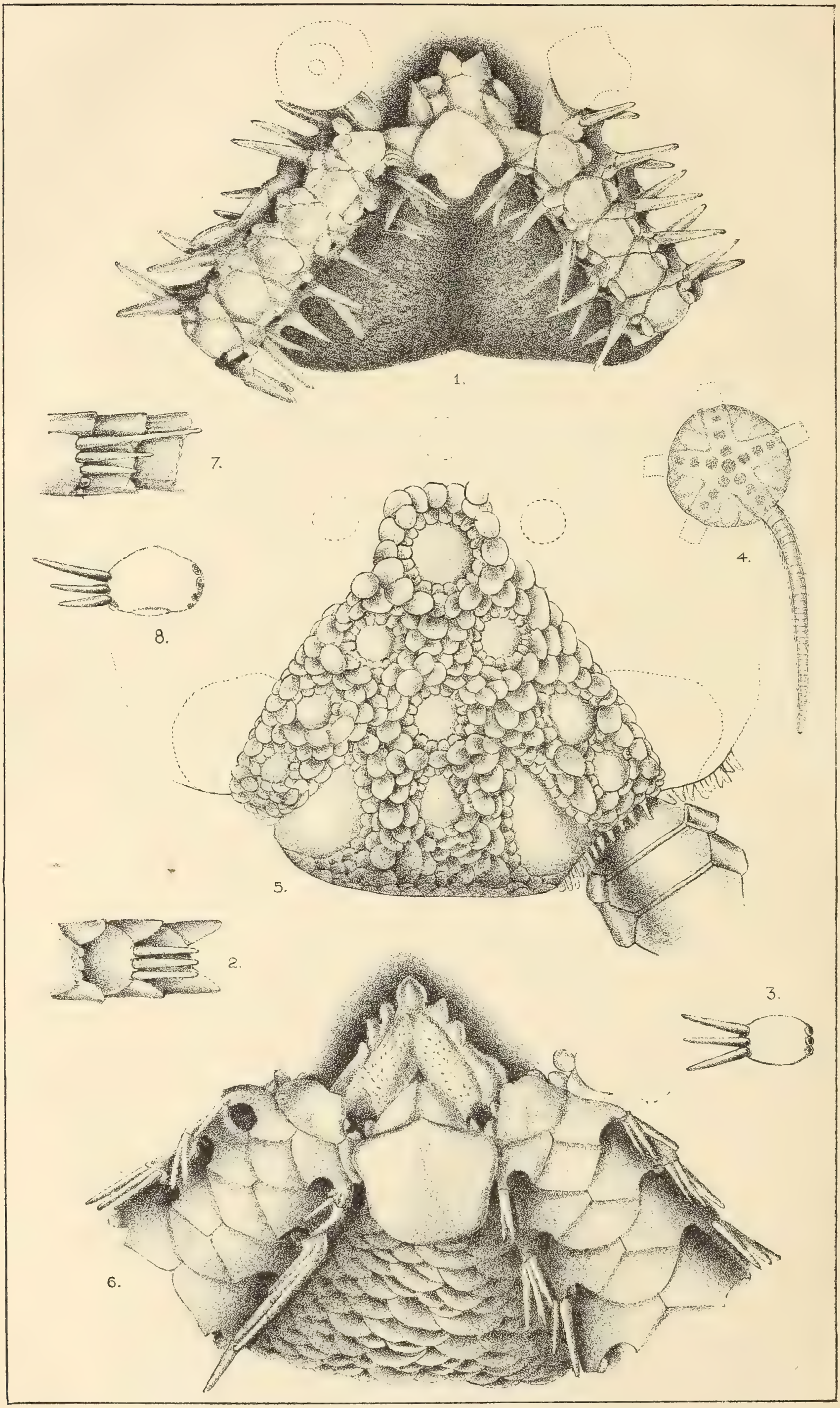


Fig. 3.



W. E. Hoyle, Del.

Scott & Ferguson Edin.

Figs. 1–3. Amphiura bellis var. tritonis nov.
„ 4–8. Ophioglypha signata, Verrill.

sum of the similar triangles on CA and CB—and this is *any* triangle on AB. (*G.*)

Finally, if any triangle, AEF, be described on AE, since AE and corresponding lines are sides of a right-angled triangle, it follows, by the result last proved, that the triangle AEF = sum of corresponding triangles; and in like manner for any triangle described on AF.

Thus the whole rectilineal figure BEF . . . . A is equal to the similar and similarly described figures on CA and BC, *which is Prop.* 31 *of Euclid*, Bk. VI. (*H.*)

It may be remarked that the following two interesting results, proved in the case of isosceles triangles, are true for any similar triangles described on the sides of ABC.

(1) If perpendiculars be drawn from the vertices G and P (fig. 1) on the hypotenuse AB, the parts of them intercepted by the sides BC and CA respectively are each equal to the altitude HF of the triangle on AB.

(2) If CH meet AB in N, and HF be perpendicular to AB, then

$$\begin{aligned} \Delta CGB &= \Delta HNB + \Delta CNF , \\ \text{and } \Delta CPA &= \Delta HNA - \Delta CNF , \\ \text{so that } \Delta CGB + \Delta CPA &= \Delta AHB . \end{aligned}$$

When ABC is isosceles, the triangle CNF disappears.

3. Report on the Ophiuroidea of the Faröe Channel, mainly collected by H.M.S. "Triton" in August 1882, with some Remarks on the Distribution of the Order. By W. E. Hoyle, M.A. (Oxon.), M.R.C.S., Naturalist to the "Challenger" Commission. (Plate VII.)

Some time ago Mr John Murray kindly placed in my hands the Ophiuroidea collected by H.M.S. "Triton" in the Faröe Channel, with the request that I would draw up a report upon them, and the object of the present paper is to communicate to the Society the results of my investigations.

The collection contains no new species, but one specimen appears to be a well-marked variety of *Amphiura bellis*, Lyman, a species

discovered by H.M.S. "Challenger" in the North Pacific. This small number of novelties does not, however, imply that the collection is deficient in importance, for, owing to the peculiar configuration of the sea-bed in this region, every dredging in it is of value; and when, as in this case, the physical conditions are carefully determined at each station, the result possesses a very great interest for students of the distribution of animal life upon the globe.

Before proceeding further, I give a list of the species collected by H.M.S. "Triton," arranged according to the stations at which they were obtained.

I have also had the opportunity afforded me by Mr Murray of examining the Ophiurids obtained by H.M.S. "Knight Errant," already recorded in the *Proceedings* of this Society,* and also a large proportion of those collected by H.M.S. "Porcupine." These last have been named by Mr Theodore Lyman, but as no list of them has yet been published, and as reference will be made to them in what follows, I think it well to enumerate them here, although the list will be far from complete, for the collection to which I have had access does not contain all the specimens collected by the "Porcupine," and especially is it deficient as regards the cruise in the Mediterranean in 1870. In a few instances the list has been supplemented by information derived from the published accounts of the "Porcupine" investigations.†

The figures following each name indicate the number of specimens caught.

The First Cruise of H.M.S. "Porcupine," 1864.

Off Valentia.‡ May 24th. Depth, 110 fathoms.

Ophiothrix pentaphyllum (Pennant), . . .	20
Ophioglypha albida (Forbes), ...	5

Lough Swilley. June 10th. Depth, 13 fathoms.

Ophioglypha lacertosa (Pennant), ...	9

* *Proc. Roy. Soc. Edin.*, vol. xi. p. 707, 1882.

† Carpenter, Jeffreys, and Thomson, *Proc. Roy. Soc. Lond.*, vol. xviii. pp. 397–492, 1870; Wyville Thomson, *Depths of the Sea*, London, 1874.

‡ The bottles containing these specimens are labelled, "'Lightning,' off Valentia," but there must be some error in this, for no dredgings were made by that vessel in this locality.

THE SECOND CRUISE OF H.M.S. "PORCUPINE," 1869.

Off Cape Clear.*

Ophioglypha lacertosa (Pennant), ... 5

Station 34. Lat. 49° 51′ N., long. 10° 12′ W. Depth, 75 fathoms. Bottom temperature, 49°·6 F. (9°·8 C.). Mud, gravel, shells.

Amphiura Chiajii, Forbes, ... 5
Ophioglypha Sarsii ? (Lütken) (*juv.*), . . . 1
Ophiopholis aculeata (O. F. Müller), ... 1

Station 37. Lat. 48° 38′ N., long. 12° 8′ W. Depth, 2435 fathoms. Bottom temperature, 36°·5 F. (2°·5 C.). Globigerina ooze.

Ophiacantha bidentata (Retzius), ... ?
Ophiocten sericeum (Forbes), ... 5

Stations 39–41.† Lat. 35° 59′–35° 57′ N., long. 5° 27′–4° 12′ W. Depth, 517–730 fathoms. Bottom temperature, 47°·0–46°·5 F. (13°·3–13°·4 C.). Ooze, sand, shells.

Ophiactis Ballii (Thompson), ... ?
Ophiacantha bidentata (Retzius), ... ?
Ophiothrix fragilis (O. F. Müller), ... ?

Station 42. Lat. 49° 12′ N., long. 12° 52′ W. Depth, 862 fathoms. Bottom temperature, 39°·7 F. (4°·3 C.). Ooze, sand, shells.

Ophiochiton tenuispinus, Lyman, ... 1

Station 43. Lat. 50° 1′ N., long. 12° 26′ W. Depth, 1207 fathoms. Bottom temperature, 37°·7 F. (3°·2 C.). Globigerina ooze.

Ophiocten sericeum (Forbes), ... 1

Station 45*a*. Lat. 51° 1′ N., long. 11° 21′ W. Depth, 180 fathoms.

Ophiomusium Lymani, Wyv. Thoms., . . . ?

* One of the following stations;—33 (Lat. 50° 38′ N., long. 9° 27′ W. Depth, 74 fathoms. Bottom temperature, 65°·2 F. [9°·8 C.]), 34 or 45 *a*.

† *Proc. Roy. Soc. Lond.*, vol. xviii. p. 431, 1870.

Ophiothrix Lütkeni, Wyv. Thoms., . . .	5
Ophioglypha lacertosa (Pennant), . . .	(many)

THE THIRD CRUISE OF H.M.S. "PORCUPINE," 1869.

Station 46. Lat. 59° 23′ N., long. 7° 4′ W. Depth, 374 fathoms. Bottom temperature, 46°·0 F. (7°·7 C.).

Ophiothrix fragilis (O. F. Müller), ...	1 *

Station 47. Lat. 59° 34′ N., long. 7° 18′ W. Depth, 542 fathoms. Bottom temperature, 43°·8 F. (6°·5 C.). Globigerina ooze, sand.

Ophiactis abyssicola (Sars), ...	22
Ophiocten sericeum (Forbes), ...	2

Station 51. Lat. 60° 6′ N., long. 8° 14′ W. Depth, 440 fathoms. Bottom temperature, 42° 0′ F. (5°·5 C.).

Ophiactis abyssicola (Sars), ...	7
Ophiacantha bidentata (Retzius), ...	1 †

Station 52. Lat. 60° 25′ N., long. 8° 10′ W. Depth, 384 fathoms. Bottom temperature, 30°·6 F. (–0°·8 C.).

Ophiopus arcticus, Ljungman, ...	6
Ophiacantha bidentata (Retzius), ...	1
Ophiactis abyssicola (Sars), ...	28

Station 54. Lat. 59° 56′ N., long. 6° 27′ W. Depth, 363 fathoms. Bottom temperature, 31°·4 F. (–0°·3 C.).

Ophiacantha bidentata (Retzius), ...	1 †
,, *abyssicola*, Sars, ...	1
Ophiactis Ballii (Thompson), ...	1
Ophiomyxa serpentaria, Lyman, ...	1
Ophiopholis aculeata (O. F. Müller), . . .	4
Ophioscolex purpureus, Düb. and Kor., . . .	2

* Possibly the young of *O. Lütkeni.*

† These specimens have six arms.

Station 57. Lat. 60° 14′ N., long. 6° 17′ W. Depth, 632 fathoms. Bottom temperature, 30°·5 F. (– 0°·8 C.)

Ophioscolex purpureus, Düb. and Kor., . . . 2

Station 60. Lat. 61° 3′ N., long. 5° 58′ W. Depth, 167 fathoms. Bottom temperature, 44°·3 F. (6°·9 C.).

Ophiopholis aculeata (O. F. Müller), . . . 3

Station 61. Lat. 62° 1′ N., long. 5° 19′ W. Depth, 114 fathoms. Bottom temperature, 45°·0 F. (7°·2 C.).

Ophiopholis aculeata (O. F. Müller), . . . 1

On the Faröe Bank.*

Ophiothrix pentaphyllum (Pennant), . . . 2
,, *fragilis* (O. F. Müller), . . . 7

Station 65. Lat. 61° 10′ N., long. 2° 21′ W. Depth, 345 fathoms. Bottom temperature, 29°·8 F. (– 1°·1 C.).

Gorgonocephalus eucnemis (Müll. and Tr.) . . . 4
Ophiacantha abyssicola, Sars, ... 3
Ophiactis abyssicola (Sars), ... 3
Ophiobyrsa hystricis, Lyman, ... 1
Ophioglypha Sarsii (Lütken), ... 2
Ophiopholis aculeata (O. F. Müller), ... 12

Station 67. Lat. 60° 32′ N., long. 0° 29′ W. Depth, 64 fathoms. Bottom temperature, 49°·1 F. (9°·5 C.).

Ophiopholis aculeata (O. F. Müller), ... 12
† *Amphiura Chiajii*, Forbes, ... 1
† *Ophiactis abyssicola* (Sars), ... 2
† *Ophioglypha Sarsii* (Lütken), ... 6
† *Ophiopholis aculeata* (O. F. Müller), ... 4

* Either Station 61, or Station 62. (Lat. 61° 59′ N., long. 4° 38′ W. Depth, 125 fathoms. Bottom temperature, 44°·6 F. [7°·0 C.]).

† The specimens bracketed were contained in a bottle labelled "Stations 67 and 68." The bottom temperature of the latter is 44° F. Depth, 75 fathoms.

Station 74. Lat. 60° 39′ N., long. 3° 9′ W. Depth, 203 fathoms. Bottom temperature, 47°·6 F. (8°·7 C.).

Amphiura borealis (Sars), ...	1
Ophiacantha abyssicola, Sars, ...	12
,, *bidentata* (Retzius), ...	15
Ophiactis abyssicola (Sars), ...	10
,, *Ballii* (Thompson), ...	4
Ophiopholis aculeata (O. F. Müller), ...	17
Ophioscolex purpureus, Düb. and Kor., . . .	3
Ophiothrix fragilis * (O. F. Müller), . . .	2

Station 77. Lat. 60° 34′ N., long. 4° 40′ W. Depth, 560 fathoms. Bottom temperature, 29°·8 F. (−1°·2 C.).

Ophiacten sericeum (Forbes), ...	16
Ophiopholis aculeata (O. F. Müller), ...	2

Station 78. Lat. 60° 14′ N., long. 4° 30′ W. Depth, 290 fathoms. Bottom temperature, 41°·5 F. (5°·3 C.).

Ophiacantha abyssicola, Sars, ...	10
Ophioglypha Sarsii (Lütken), ...	1
Ophiopholis aculeata (O. F. Müller), ...	10
Ophioscolex glacialis, Müll. and Tr., ...	1

Station 82. Lat. 60° 0′ N., long. 5° 13′ W. Depth, 312 fathoms. Bottom temperature, 41°·4 F. (5°·2 C.).

Ophiacantha abyssicola, Sars, ...	9
Ophioglypha Sarsii (Lütken), ...	8
Ophiopholis aculeata (O. F. Müller), ...	30
Ophioscolex glacialis, Müll. and Tr., ...	2
,, *purpureus*, Düb. and Kor., . . .	16

Station 87. Lat. 59° 35′ N., long. 9° 11′ W. Depth, 767 fathoms. Bottom temperature, 41°·4 F. (5°·2 C.).

Ophioscolex purpureus, Düb. and Kor., . . .	4

* Possibly the young of *O. Lütkeni*.

Station 88. Lat. 59° 26′ N., long. 8° 23′ W. Depth, 705 fathoms. Bottom temperature, 42°·6 F. (5°·9 C.).

Ophiocten sericeum (Forbes), (*juv.*), . . . 20

Station 89? Lat. 59° 38′ N., long. 7° 46′ W. Depth, 445 fathoms. Bottom temperature, 45°·5 F. (7°·5 C.).

Asteronyx Lovéni, Müll. and Tr., ... ?

Station 90. Lat. 59° 41′ N., long. 7° 34′ W. Depth, 458 fathoms. Bottom temperature, 45°·2 F. (7°·3 C.).

Amphiura filiformis (O. F. Müller), ... 2
Ophiacantha abyssicola, Sars (*juv.*), . . . 1
Ophiactis abyssicola (Sars), (*juv.*), ... 31
Ophioglypha albida (Forbes), ... 1
Ophiothrix fragilis (O. F. Müller), ... 3

The Minch. Depth, 60–80 fathoms.

Amphiura Chiajii, Forbes, ... 3
Ophiothrix pentaphyllum (Pennant), . . . 1
Asteronyx Lovéni, Müll. and Tr., ... 6

THE CRUISE OF H.M.S. "PORCUPINE" IN THE MEDITERRANEAN, 1870.

Station 13. Vigo Bay. Depth, 220 fathoms. Bottom temperature, 52° F. (11° C.).

Amphiura filiformis (O. F. Müller), ... 45

Adventure Bank, South of Sicily. Depth, 30–250 fathoms.

Ophioglypha lacertosa (Pennant), ... 1

THE CRUISE OF H.M.S. "TRITON."

Station 1. August 4, 1882. Lat. 59° 51′ 30″ N., long. 6° 21′ W. Depth, 240 fathoms. Bottom, sand and gravel. Bottom temperature, 47°·5 F. (8°·7 C.). Dredge.

Ophiactis Ballii (Thompson), ... 1

Station 2. August 5, 1882. Lat. 59° 37′ 30″ N., long. 6° 49′ W. Depth, 530 fathoms. Bottom, mud. Bottom temperature, 46°·2 F. (8°·0 C.). Trawl.

Ophiopholis aculeata (O. F. Müller), . . .	2

Station 3. August 8, 1882. Lat. 60° 39′ 30″ N., long. 9° 6′ W. Depth, 87 fathoms. Bottom, sand and shells. Bottom temperature, 49°·25 F. (9°·6 C.). Dredge.

Ophiocoma nigra (O. F. Müller), ...	9
Ophioglypha lacertosa (Pennant), ...	3
Ophiopholis aculeata (O. F. Müller), . . .	51
Ophiothrix fragilis (O. F. Müller), ...	74

Station 4. August 8, 1882. Lat. 60° 20′ 15″ N., long. 8° 25′ 30″ W. Depth, 327 fathoms. Bottom, stones. Bottom temperature, 31°·75 F. (−0°·7 C.). Trawl.

Ophiactis abyssicola (Sars), ...	4

Station 5. August 9, 1882. Lat. 60° 11′ 45″ N., long. 8° 15′ W. Depth, 433 fathoms. Bottom, hard ground. Bottom temperature, 43°·5 F. (6°·5 C.). Trawl.

Gorgonocephalus eucnemis (Müll. and Tr.), . .	7
Ophiacantha spectabilis, Sars, ...	2
Ophiactis abyssicola (Sars), ...	5
Ophioglypha signata, Verrill, ...	3
Ophiopholis aculeata (O. F. Müller), . . .	16
Ophioscolex purpureus, Düb. and Kor., . . .	14

Station 6. August 17, 1882. Lat. 60° 9′ N., long. 7° 16′ 30″ W. Depth, 466 fathoms. Bottom, stones. Bottom temperature, 29°·75 F. (−1°·2 C.). Dredge.

Ophioglypha signata, Verrill, ...	35

Station 8. August 22, 1882. Lat. 60° 18′ N., long. 6° 15′ W.

Depth, 640 fathoms. Bottom, mud. Bottom temperature, 30° F. (– 1°·0 C.). Trawl twice.

Ophioglypha signata, Verrill, ... 27

Station 9. August 23, 1882. Lat. 60° 5′ N., long. 6° 21′ W. Depth, 608 fathoms. Bottom, mud. Bottom temperature, 30° F. (– 1°·0 C.). Trawl.

Ophioglypha signata, Verrill, ... 15

Off Castle Walker, Loch Linnhe, 35–37 fathoms.

Amphiura Chiajii, Forbes, ... 11.

Station 10. August 24, 1882. Lat. 59° 40′ N., long. 7° 21′ W. Depth, 516 fathoms. Bottom, mud. Bottom temperature, 56°·25 F. (13°·55 C.). Trawl.

Amphiura bellis, Lyman, var. *tritonis*, nov., . .	1
Ophiactis abyssicola (Sars), ...	3
Ophioglypha aurantiaca, Verrill, ...	35
Ophiothrix fragilis (O. F. Müller), ...	2
Young specimens undetermined, ...	3

Station 11. August 28, 1882. Lat. 59° 29′ 30″ N., long. 7° 13′ W. Depth, 555 fathoms. Bottom, ooze. Bottom temperature, 45° 5′ F. (7°·6 C.). Dredge and trawl.

Amphiura filiformis (O. F. Müller), . . .	1
Ophiactis abyssicola (Sars), ...	1
Ophioglypha aurantiaca, Verrill, ...	6

Station 13. August 31, 1882. Lat. 59° 51′ 2″ N., long. 8° 18′ W. Depth, 570 fathoms. Bottom, ooze. Bottom temperature, 45°·7 F. (7°·7 C.). Dredge and Trawl.

Ophioglypha aurantiaca, Verrill, ...	3
Young specimen undetermined, ...	1

A description of the one new form may be conveniently appended here, along with a few notes upon one or two other species.

Amphiura bellis, Lym., var. *tritonis*. (Pl. VII. figs. 1–3.)

Diameter of disk, 12 mm. Arms, long and slender, 11 cm. Width of arm close to disk, without spines, 2 mm. Two mouth papillæ on either side; one large trapezoidal at the apex of the mouth angle, one of its sides coinciding with the corresponding margin of its fellow, the ten papillæ almost enclosing the circle of the mouth; the other mouth papilla is at the commencement of the oral process; is acutely pointed and triangular, and is succeeded immediately by a diamond-shaped scale, which covers the opening of the first tentacle. A supplementary scale was noticed at one mouth-angle (fig. 1).

Mouth shields heart-shaped, one subpentagonal. Side mouth shields appear to be triangular; they do not project inwards beyond the median shields, and they meet each other in the position usually occupied by the first under-arm plate, which is absent. The other arm-plates are rectangular, with the inner and outer margins somewhat rounded; farther out on the arms they form an angle, so that the plate is hexagonal; the lateral margins straight and coincident with the attached margin of one of the tentacle scales. Side arm-plates slightly prominent where the spines are attached, not meeting in the middle line either above or below. Upper arm-plates transversely oval, but the proximal margin, instead of being evenly curved, forms an angle.

Disk flat, thin, covered with small swollen overlapping scales, which are coarser and radially elongated near the radial shields.

Radial shields, wedge-shaped, very long, about four times as long as wide, pointed at the proximal extremity, truncated distally, completely separated from each other, except perhaps at the extreme outer end, by a median and one or two lateral rows of elongated scales. Interbrachial spaces in the under surface covered with similar small scales; three, or sometimes at the proximal end of the arm four, straight tapering bluntly-pointed arm-spines.

Two tentacle scales, one towards the axis of the arm, elongated, semi-oval; one on the proximal margin of the aperture, shorter and more nearly circular.

Colour, yellowish-grey, with five rather indefinite radial markings on the dorsal surface of the disk.

The typical *Amphiura bellis* differs from this in having one short stout blunt papilla on either side of the base of the mouth angle.

It has also subtriangular mouth shields, and the lateral mouth shields do not meet each other in the middle line.

The mouth papillæ are of a different shape. A first under arm bone is present, and the tentacle scales of the first pair are spiniform and rather conspicuous.

This single specimen is worthy of special notice, because the species has been only known hitherto from specimens collected by the "Challenger" at Stations 174, near the Fiji Islands, and 232 and 236, off Japan. It is interesting to notice that *Asteronyx Lovéni* is also common to the north European seas and those of Japan, and a relation has been traced by Drs Gwyn Jeffreys, and Günther between the mollusca and fishes of Japan and the North Atlantic and Mediterranean.*

Ophioglypha aurantiaca, Verrill.

Ophioglypha aurantiaca, Verrill, *Amer. Jour. Sci. and Arts*, vol. xxiii. p. 141, 1882. Lyman, *Bull. Mus. Comp. Zoöl.*, vol. x. No. 6, p. 240 (with fig.), 1883.

The mouth shield has the inner angle almost a right angle; the outer edge is not nearly straight, but with a re-entering angle. The teeth papillæ are usually four. As in Professor Verrill's specimens, the arms have all been broken; the longest measured twice the diameter of the disk. The arm-spines are three; the uppermost is the longest, and is a little longer than the arm-joints, and the second is about two-thirds the length of the first; the third is still shorter; the tentacle-scale is close to the arm-spines, and appears to form part of the same series with them; there is only one tentacle-scale, except in the proximal portion of the arm, where there are two; where this is the case, the outer is spiniform, the inner scale like. The margin of the genital slit is finely serrated. The two or three proximal tentacle pores have sometimes three tentacle scales, close beside which are two small spines, about equal to them in size.

* *Journ. Linn. Soc. Lond.*, vol. xii. pp. 100–109, 1874.

Average dimensions,—diameter of disk, 12–15 mm.; thickness rarely more than 5 mm.

Ophiactis Ballii. The bathymetrical range of this species is extended to 730 fathoms.

Ophiocten sericeum was dredged by H.M.S. "Porcupine" at six stations, the depths varying from 542 to 2435 fathoms, its bathymetrical range being thereby greatly extended.

Ophiopholis aculeata. Bathymetrical range extended to 560 fathoms.

Ophiothrix fragilis. Bathymetrical range extended to 516 fathoms.

Gorgonocephalus eucnemis and *Ophiacantha spectabilis* are new to British seas.

Ophiactis abyssicola. This species has not been previously obtained in British seas, and its bathymetrical range is extended from 400 to 767 fathoms.

Ophioscolex purpureus. This species is also an addition to the British fauna, and its bathymetrical range is extended from 200 to 767 fathoms.

Ophioglypha signata, Verrill (Pl. VII. figs. 4–8), was first discovered by Professor Verrill off the north-eastern coast of the United States (100–258 fathoms),* and has again been recorded by Mr Lyman in the *Proceedings* of this Society (vol. xi. p. 707). As no figure of it has yet been published, I have given one on the accompanying plate.

Amphiura filiformis. Bathymetrical range extended to 555 fathoms.

These few matters of systematic and descriptive interest being disposed of, we may proceed to discuss the distributional problems suggested by the material in hand. The importance of the Faröe Channel as a field for zoological investigation lies, as is well known, in the fact that there are here two areas not far separated, and resembling each other in depth and physical conditions generally, save only that in one the average temperature of the bottom water

* *Amer. Jour. Sci. and Arts*, vol. cxxiii. pp. 218, 220, 1882.

is some 10–15° F. higher than in the other. We have thus two areas in which all factors influencing the distribution of animals are approximately eliminated, save and excepting that of temperature, so that here, if anywhere, we may hope for an opportunity of determining the influence due to this important factor.

With the view of investigating this matter, so far as the Ophiuroids are concerned, the table on the next page has been drawn up, which includes all the results obtained by H.M.S. "Porcupine," "Knight Errant," and "Triton" which are applicable to the problem under discussion. In order to render the results strictly comparable, only those stations are considered which are clearly within one area or the other, none, of course, being admitted which are at a less depth than the top of the Wyville-Thomson Ridge, that is, about 300 fathoms. The depth and bottom temperature of each station are given, and the number of specimens obtained at each is shown by the figures in the several columns.

It will be obvious that in attempting to draw conclusions from such a table, the utmost caution must be observed; the numbers are so small, that any extensive series of dredgings will be sure to alter them very considerably. For instance, the whole of the expeditions together, prior to the "Triton," only obtained one specimen of *Ophioglypha aurantiaca*, while only three dredgings on that cruise yielded together forty-five specimens.

Still as no further data are at present available, the best use possible must be made of these, it being understood that the results are only provisional. It appears then, that while eight species were found both in the warm and cold areas, six were peculiar to the latter and six to the former.

These facts suggest that there are certain forms which flourish in warmer, whilst others are better adapted to colder waters; but in order to confirm this view, it will be well to state what is known of the distribution, with respect to temperature, of each of the species in question in other localities; unfortunately our knowledge upon this point is very fragmentary, because it is only of recent years that dredgings have been made, while, at the same time, accurate physical observations have been taken, but such facts as I have been able to collect are given in the following paragraphs.

Amphiura bellis, Lym., has previously been found only at three

TABLE showing the Distribution of the

WARM AREA.													
		PORCUPINE. 1869.					KNIGHT ERRANT. 1880.		TRITON. 1882.				
	STATION, ...	46	47	51	87	90	5	7	2	5	10	11	13
	DEPTH, ...	374	542	440	767	458	515	530	530	433	516	555	570
	BOTTOM TEMPERATURE (C),	$7°\cdot7$ ...	$6°\cdot5$ ...	$5°\cdot5$ ...	$5°\cdot2$ ...	$7°\cdot3$ ...	$6°\cdot8$ $8°\cdot1$	$8°\cdot1$ ...	$8°\cdot0$ $8°\cdot0$	$6°\cdot5$ $6°\cdot5$	$7°\cdot8$ $8°\cdot1$	$7°\cdot6$ $7°\cdot6$	$7°\cdot7$ $7°\cdot7$
Warm Area only.	Amphiura bellis var tritonis,	.	.	.	.	.	.	.	.	.	1	.	.
	,, filiformis, . .	.	.	.	.	2	.	.	.	.	.	1	.
	Ophiacantha spectabilis, .	.	.	.	.	.	.	.	.	2	.	.	.
	Ophioglypha albida, . .	.	.	.	.	1	.	.	.	.	.	.	.
	,, aurantiaca, .	.	.	.	.	.	.	1	.	.	35	6	3
	Ophiothrix fragilis, . .	1	.	.	.	3	.	.	.	.	2	.	.
Common to both Areas.	Gorgonocephalus eucnemis, .	.	.	.	.	.	.	.	.	7	.	.	.
	Ophiacantha abyssicola .	.	.	.	.	1	.	.	.	.	.	.	.
	,, bidentata, .	.	.	1	.	.	2	.	.	.	.	.	.
	Ophiactis abyssicola, . .	.	22	7	.	31	2	10	.	5	3	1	.
	Ophiocten sericeum, . .	.	2	.	.	.	.	.	.	.	.	.	.
	Ophioglypha signata, . .	.	.	.	.	.	.	.	.	3	.	.	.
	Ophiopholis aculeata, . .	.	.	.	.	.	.	.	2	16	.	.	.
	Ophioscolex purpureus, .	.	.	.	4	.	.	.	.	14	.	.	.
Cold Area only.	Ophiobyrsa hystricis, . .	.	.	.	.	.	.	.	.	.	.	.	.
	Ophiomyxa serpentaria, .	.	.	.	.	.	.	.	.	.	.	.	.
	Ophiopus arcticus, . .	.	.	.	.	.	.	.	.	.	.	.	.
	Ophiactis Ballii, . . .	.	.	.	.	.	.	.	.	.	.	.	.
	Ophioglypha Sarsii, . .	.	.	.	.	.	.	.	.	.	.	.	.
	Ophioscolex glacialis, . .	.	.	.	.	.	.	.	.	.	.	.	.

OPHIUROIDEA in the Faröe Channel.

COLD AREA.											
PORCUPINE. 1869.					KNIGHT ERRANT. 1880.		TRITON. 1882.				
52	54	57	65	77	2	8	4	6	8	9	
384	363	632	345	560	375	540	327	466	640	608	
−0°·8	−0°·3	−0°·8	−1°·1	−1°·2	−0°·6	−2°·1	0°·0	−1°·0	−1°·0	−1°·0	
...	...	...	...	...	−0°·6	−0°·9	−0°·3	−1°·3	−1°·0	−1°·0	
.	.	.	.	.	.	.	.	.	.	.	Warm Area only.
.	.	.	.	.	.	.	.	.	.	.	
.	.	.	.	.	.	.	.	.	.	.	
.	.	.	.	.	.	.	.	.	.	.	
.	.	.	.	.	.	.	.	.	.	.	
.	.	.	.	.	.	.	.	.	.	.	
.	.	.	4	.	.	.	.	.	.	.	Common to both Areas.
.	1	.	3	.	.	.	.	.	.	.	
1	1	.	.	.	.	.	.	.	.	.	
28	.	.	3	.	22	.	4	.	.	.	
.	.	.	.	16	.	.	.	.	.	.	
.	.	.	.	.	.	7	.	35	27	15	
.	4	.	12	2	.	.	.	.	.	.	
.	2	2	.	.	.	.	.	.	.	.	
.	.	.	1	.	.	.	.	.	.	.	Cold Area only.
.	1	.	.	.	.	.	.	.	.	.	
6	.	.	.	.	.	.	.	.	.	.	
.	1	.	.	.	.	.	.	.	.	.	
.	.	.	2	.	.	.	.	.	.	.	
.	.	.	.	.	1	.	.	.	.	.	

TABLE showing the Distribution of the OPHIUROIDEA in the Faröe Channel.

		WARM AREA.												COLD AREA.											
		PORCUPINE. 1869.					KNIGHT ERRANT. 1880.		TRITON. 1882.					PORCUPINE. 1869.					KNIGHT ERRANT. 1880.		TRITON. 1882.				
	STATION,	46	47	51	87	90	5	7	2	5	10	11	13	52	54	57	65	77	3	8	4	6	8	9	
	DEPTH,	374	542	440	767	458	515	530	530	433	516	555	570	384	363	632	345	560	375	540	327	466	640	608	
	BOTTOM TEMPERATURE (C),	7°·7 ...	6°·5 ...	5°·5 ...	5°·2 ...	7°·3 ...	6°·8 8°·1	8°·1 ...	8°·0 8°·0	6°·5 6°·5	7°·8 8°·1	7°·6 7°·6	7°·7 7°·7	−0°·8 ...	−0°·3 ...	−0°·8 ...	−1°·1 ...	−1°·2 ...	−0°·6 −0°·6	−2°·1 −0°·9	0°·0 −0°·3	−1°·0 −1°·3	−1°·0 −1°·0	−1°·0 −1°·0	
Warm Area only.	Amphiura bellis var tritonis,	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	Warm Area only.
	„ filiformis,	.	.	.	.	2	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	
	Ophiacantha spectabilis,	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	
	Ophioglypha albida,	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	
	„ aurantiaca,	.	.	.	.	.	.	1	.	.	35	6	3	.	.	.	.	.	.	.	.	.	.	.	
	Ophiothrix fragilis,	1	.	.	.	3	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	
Common to both Areas.	Gorgonocephalus eucnemis,	.	.	.	.	.	.	.	.	7	.	.	.	.	.	.	4	.	.	.	.	.	.	.	Common to both Areas.
	Ophiacantha abyssicola	.	.	.	.	1	.	.	.	.	.	.	.	.	1	.	3	.	.	.	.	.	.	.	
	„ bidentata,	.	.	1	.	.	2	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	
	Ophiactis abyssicola,	.	22	7	.	31	2	10	.	5	3	1	.	28	.	.	3	.	22	.	4	.	.	.	
	Ophiocten sericeum,	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	16	.	.	.	.	.	.	
	Ophioglypha signata,	.	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	7	.	35	27	15	
	Ophiopholis aculeata,	.	.	.	.	.	.	.	2	16	.	.	.	.	4	.	12	2	.	.	.	.	.	.	
	Ophioscolex purpureus,	.	.	.	4	.	.	.	.	14	.	.	.	.	2	2	.	.	.	.	.	.	.	.	
Cold Area only.	Ophiobyrsa hystricis,	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	Cold Area only.
	Ophiomyxa serpentaria,	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	
	Ophiopus arcticus,	.	.	.	.	.	.	.	.	.	.	.	.	6	.	.	.	.	.	.	.	.	.	.	
	Ophiactis Ballii,	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	
	Ophioglypha Sarsii,	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	
	Ophioscolex glacialis,	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	

"Challenger" stations in the Pacific, viz., Station 174, bottom temperature 3°·7 C. (38°·5 F.); 232, bottom temperature 5° C. (40°·4 F.); 236, bottom temperature 2°·8 C. (37°·2 F.) In addition, it must be borne in mind that the variety here described might prove on further examination to be a new species.

Amphiura filiformis, has not (except in the instances quoted in the table) been reported from depths greater than 150 fathoms, so that it is presumably a warm water species.

Ophiacantha spectabilis occurs on the Norwegian coast, but has not been met with at depths greater than 100 fathoms.

Ophioglypha albida occurs in the British, Danish, and Norwegian shallow waters, and has not been known to live at any depth greater than 500 fathoms. It is found also in the Mediterranean; hence it is probably a warm water species.

Ophioglypha aurantiaca, in addition to the localities noted in the table, has only been observed off Martha's Vineyard, North-East America, and at two of the "Blake" Stations, depths 466 and 524, and bottom temperature, 40° and 39°·5 F. respectively.

Ophiothrix fragilis has been obtained at various points on the British and Norwegian coasts, from depths not exceeding 150 fathoms, so that in default of precise temperature observations, it may be regarded as a species proper to warm rather than cold water.

Gorgonocephalus eucnemis was found by the "Willem Barents" at two localities, at both of which the temperature of the water was below the freezing point; and it is also found off the coast of Greenland, so that obviously it has no more claim to be considered a warm than a cold water species.

Ophiacantha abyssicola, occurs off the Lofoten Islands above the 300-fathom line, which is within the warm area, as determined by the Norwegian North Sea explorers. It has also been dredged at one of the "Blake" Stations, E.S.E. of New York, from a depth of 304 fathoms. Bottom temperature, 49°·5 F. (9°·7 C.).

Ophiobyrsa hystricis and *Ophiomyxa serpentaria*, have at present only been found in the localities noted above.

Ophiopus arcticus, is known from Spitzbergen and Norway down to the 400 fathom line.

Ophiactis Ballii is found in shallow water off the British and

Scandinavian coasts, and in the North Atlantic, 40–50 fathoms; except in the present instance it has not been found below 150 fathoms, which distribution would seem to indicate that it is a denizen of warm as well as of cold areas, and should by rights be placed among the species "common to both areas."

Ophioglypha Sarsii has also been obtained by the "Challenger" off the east coast of North America at one station (49, depth 83 fathoms, bottom temperature 1°·8 C. [36° F.]), and at four stations by the "Blake," at depths varying from 44 to 306 fathoms, and bottom temperatures 40°·5 to 51° F. It has also been obtained off the coast of Greenland, in Smith's Sound, and off Spitzbergen, so that it would appear to be at home both in cold and warm waters.

Ophioscolex glacialis occurs also off Spitzbergen and the Arctic, European, and American seas generally. It was dredged by the "Willem Barents" at two stations, at both of which the bottom temperature was below the freezing point, so that it may be regarded as a well-marked cold water species.

From these additional data it would seem that the species classed as "peculiar to the warm area" have established for themselves a fair claim to that designation; while of those marked "peculiar to the cold area," two (*Ophiactis Ballii* and *Ophioglypha Sarsii*) must be removed to the category of "common" forms.

We have remaining then six forms peculiar to the warm, four peculiar to the cold, and ten common to both warm and cold water, a result which decidedly favours the conclusion that temperature is an important factor in determining the distribution of these animals.

Having ascertained to what extent the Ophiuroid faunas of the two areas of the Faröe Channel differ from each other, it will be interesting to examine how they are severally related (1) to the shallow-water forms of surrounding regions, that is to say, to those from the British and Norwegian shores down to 200 fathoms; (2) to the forms of more northern seas (Greenland, Spitzbergen, Barents Sea); and (3) to those inhabiting the cold water off the north-eastern coast of North America.

(1) *Comparison of the* Ophiuroidea *from the Faröe Channel with those from the British and Norwegian Shores.*

Herewith I give a list of the Norwegian Ophiuroidea as full as I have been able to compile :—

Astrophytidæ.

B. *Asteronyx Lovéni*, M.
*† *Gorgonocephalus eucnemis*, M.
,, *Lamarckii*, M., W.
B. ,, *Linckii*, M.

Ophiuridæ.

Amphiura borealis, S.
B. ,, *Chiajii*, M., W.
*B. ,, *filiformis*, M., W.
B. ,, *elegans*, M., W.
*† *Ophiacantha abyssicola*, M., S.
,, *anomala*, S.
*† ,, *bidentata*, W., S.
* ,, *spectabilis*, W., S.
†B. *Ophiactis Ballii*, M., W.
,, *claviger*, W.
*† ,, *abyssicola*, M., W.
B. *Ophiocnida brachiata*, L. ?
B. *Ophiocoma nigra*, M., W.
*† *Ophiocten sericeum* (*Ophioglypha gracilis*), S.
B. *Ophioglypha affinis*, M., W.
*B. ,, *albida*, M.
,, *carnea*, M., W.
B. ,, *lacertosa* (*texturata*), M.
B. ,, *robusta*, M.
†B. ,, *Sarsii*, M.
B. *Ophiopeltis securigera*, M.
*†B. *Ophiopholis aculeata*, M., W.
† *Ophiopus arcticus*, L.
† *Ophioscolex glacialis*, M.

*†B. *Ophioscolex purpureus*, M.
*B. *Ophiothrix fragilis*, M., W.

* Found in the warm area. † Found in the cold area. *† Found in both areas.
M = Sars, M., "Oversigt af Norges Echinodermer," 1861.
S = Sars, G. O., "Nye Echinodermer," *Vid.-Selsk. Forhandl.*, 1871.
W = A collection formerly in possession of the late Sir Wyville Thomson, believed to have been sent to him by Prof. Sars.
L = Lyman.
B = Also belonging to the British shallow-water fauna (down to 200 fathoms). Hoyle, *Proc. Roy. Phys. Soc. Edin.*, vol. viii. pp. 135–155, 1884.

When this list is compared with those given in the preceding table, it is found that every form mentioned therein occurs also off the Norwegian coast, with the exception of three species (*Amphiura bellis*, var., *Ophioglypha aurantiaca*, and *O. signata*) from distant parts of the world, and two (*Ophiobyrsa hystricis* and *Ophiomyxa serpentaria*), described from single specimens in this locality.

Of those which are also found in the British shallow water it will be seen that three are among those peculiar to the warm area, two are common, and two are peculiar to the cold area. Of these last, however, it must be noted that *Ophioglypha Sarsii* has only been found in British seas in moderately deep water off the Shetlands; and if we exclude this as a doubtful inhabitant of our shallow water, it would appear that the British coast forms are more nearly related to those from the warm than those from the cold area.

With respect to the Norwegian coast forms no such relation can be traced, which may probably be explained by the fact that Norway, with its great extent of indented coast-line with islands and fiords, has a great variety of physical conditions, and so provides fitting homes for creatures of very diverse habit.

(2) *Comparison of the Faröe Channel* Ophiuroidea *with those from the Arctic Seas.*

The following is as complete a list as I have been able to compile of the Ophiuroidea hitherto recorded from the Arctic seas; that is, from Greenland, Spitzbergen, and the Barents Sea:—

Gorgonocephalus Agassizii, DS., L.
* ,, *eucnemis*, L., H.
,, *Lamarckii*, L.

Amphiura Holbölli, DS., L.
*† *Ophiacantha bidentata*, DS., L., H.
Ophiocoma nigra, H.
*† *Ophiocten sericeum*, DS., L., H.
Ophioglypha lacertosa, H.
„ *nodosa*, L.
„ *robusta*, DS., L., H.
† „ *Sarsii*, DS., L., H.
„ *Stuwitzii*, DS., L.
*† *Ophiopholis aculeata*, DS., L., H.
Ophiopleura arctica, DS., D., H.
„ *borealis*, Da.
† *Ophiopus arcticus*, L.
† *Ophioscolex glacialis*, L., H.

* Found in the warm area. † Found in the cold area. *† Found in both areas.

D = Duncan, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. ii, p. 266, 1877.

Da = Danielsen, *Nyt Magazin for Naturvid.*, p. 33, 1877.

DS = Duncan and Sladen, *A Memoir of the Echin. of the Arctic Sea*, London, 1881.

L = Lutken, "Additamenta ad Historiam Ophiuroidarum," *Vidensk. Selsk. Skrif.*, Bd. v, p. 28, 1858, and in *Arctic Manual*, 1875.

H = Hoffmann, "Die Echinodermen gesammelt während der Fahrten des 'Willem Barents,'" *Niederländ. Archiv f. Zool.*, Suppl.-Bd. i, Lief. 3, 1882.

From which list it appears that *six* of the northern Ophiuroids are found also in the cold area, whilst only *four* occur also in the warm; or, excluding the three species which are common to the two areas, we have *three* species common to the northern seas and the cold area, and only *one* common to these and the warm area; in addition to which it must be remembered, that of the six species above enumerated as "peculiar to the cold area," two (*Ophiobyrsa hystricis* and *Ophiomyxa serpentaria*) have been found in that locality alone, and so are not available for purposes of comparison, while of the remaining four three form part of the northern fauna; all these facts show, as clearly as can be expected from such small numbers, how much more closely this fauna resembles that of the cold than that of the warm area.

(3) *Comparison of the Faröe Channel* Ophiuroidea *with those from the Eastern Coast of North America.*

As regards the north-eastern coast of North America, the dredgings of the "Blake" and other vessels have made us acquainted with a long list of Ophiurans from that region; of these only such as are of importance for the question immediately in hand are enumerated in the subjoined list—

**Gorgonocephalus eucnemis*, V.
*†*Ophiacantha bidentata*, B., C., V.
†*Ophioglypha Sarsii*, B., C.
* „ *aurantiaca*, B.
*† „ *signata*, V.
*†*Ophiopholis aculeata*, B., C., V.
†*Ophioscolex glacialis*, B., V.

* Found in the warm area. † Found in the cold area. *† Found in both areas.

V = Verrill, *Amer. Journ. Sci. and Arts*, vol. cxvi. p. 373, 1878; vol. cxxiii. p. 218, 1882.
B = "Blake," Lyman, *Bull. Mus. Comp. Zoöl.* vol. x., No. 6, 1883.
C = "Challenger," Lyman, *Zool. Chall. Exp.*, part. xiv., 1882.

In the first place, it must be noted that the water in which these species were found is not cold as compared with the cold water of the Faröe Channel; the lowest temperature, that namely of seven stations at which *Ophiacantha bidentata* was obtained, being 38°–39° F.; while the remaining stations range from $40\frac{1}{2}$°–51° F., which is as high on the average as the greater part of the warm area of the Faröe Channel. It is seen, too, that whilst five species are common to this coast and the warm area of the Faröe Channel, just the same number are common to it and the cold area. So that we have no ground for asserting that the fauna of this coast is more intimately connected with the cold area than with the warm; indeed, one haul of the dredge might suffice to turn the balance either way.

I understand that the study of other groups of animals has shown such a relation to subsist, but we must await further investigation for any decisive evidence on the part of the Ophiuroids.

The Relation of the Ophiuroid Fauna to the Nature of the Bottom.

While investigating the "Triton" collection, it occurred to me that results of some interest might be obtained by attempting to trace the manner in which the Ophiuroids are distributed with respect to the nature of the bottom. It was obvious at the outset that such an inquiry would be beset with great difficulties, owing to the impossibility of entirely eliminating the influence of the depth and other conditions.

As a preliminary step, the distribution lists of Mr Lyman's "Report on the Challenger Ophiuroidea"* were analysed, the indications as to the nature of the bottom being taken from a revised list of stations which has been prepared for publication in the "Narrative of the Cruise of H.M.S. 'Challenger.'" The results are expressed in the accompanying table, in which are given the number of dredgings which were made upon each deposit, the number of cases in which Ophiuroids were obtained, and the relation of the latter number to the former expressed as a percentage—

	Red clay.	Glob. ooze.	Red mud.	Pterop. ooze.	Vol-canic mud.	Coral mud.	Blue and green mud.	TOTAL.
Ophiuroids found, . . .	5	14	3	4	14	11	46	120
Number of dredgings, .	38	55	11	10	30	19	79	276
Percentage, . .	13	25	27	40	47	58	58	43

The most striking fact presented by this table is that Ophiuroids are not commonly met with on those deposits which are characteristic of great depth, such as the red clay and Globigerina ooze; while they are frequent upon the shallower bottoms made up of coral mud and the blue and green muds which are composed of continental detritus; in other words, it shows (especially when taken in connection with the elaborate bathymetrical tables given in Mr Lyman's Report) that, as a rule, the abundance of Ophiuroids is

* *Zool. Chall. Exp.*, part xiv., 1882.

in inverse ratio to the depth, although, of course, it by no means excludes the possibility of other factors influencing their distribution.

It is clear, then, that the only way of obtaining any satisfactory evidence on this point will be to take groups of different deposits of the same depth, and compare them with respect to their richness in Ophiurans. In many cases the range in depth of the deposits is not sufficient to allow of this; but in some few instances it is possible.

For example, dredgings were made on red clay at depths varying from 2250 to 3875 fathoms, and on Globigerina ooze at from 1090 to 2650 fathoms; so that we may take for comparison those instances of each which lie between 2250 and 2650 fathoms.

Within these limits of depth the result is found to be—

	Globigerina ooze.	Red clay.
Ophiuroids present at . .	1 . . .	5 stations.
Number of dredgings, . .	9 . . .	19

Whence it would seem that Ophiurans are nearly three times as widely spread on the red clay as on the Globigerina ooze.

These figures are so strikingly at variance with those obtained from a consideration of the whole voyage that it is quite clear that there must be some flaw in the argument, which is probably to be found in the fact that the Globigerina ooze stations under consideration are the deepest examples of that deposit, while the red clay stations are the shallowest; and from the general law of distribution according to depth, above alluded to, we should expect some such result as this to take place.

None of the other deposits offer any adequate number of stations at equal depths for comparison; so that it would seem that at present we have no sufficient data on which to base any safe conclusions as to the influence of the nature of the bottom on the presence or absence of these animals, although it is highly probable that such an influence is exerted.

Possibly future investigations may make us acquainted with two areas which, being comparable in other respects, differ in the nature of the deposits forming their bottoms.

In conclusion, I must express my indebtedness to Dr P. H. Carpenter for a quantity of valuable information from his journal relative to the dredgings of H.M.S. "Porcupine," and to Mr Theodore Lyman for his courtesy in answering some questions which I addressed to him.

EXPLANATION OF PLATE.

Figs. 1–3. *Amphiura bellis*, Lyman, var. *tritonis*, nov.
1. Under surface of disk.
2. Side view of arm.
3. Transverse section of arm.

Figs. 4–7. *Ophioglypha signata*, Verrill.
4. Upper surface, natural size.
5. Upper surface of disk.
6. Under surface of disk.
7. Side view of arm.
8. Transverse section of arm.

4. On the Principles of Economics. By Mr Geddes. Part V. Psychological.

Monday, 7th July 1884.

ROBERT GRAY, Esq., Vice-President, in the Chair.

The following Communications were read :—

1. A Problem on Point-Motions for which a Reference-Frame can so exist as to have the Motions of the Points, relative to it, Rectilinear and Mutually Proportional. By Prof. James Thomson.

In a paper read in this Society on the 3rd of March last, "On the Law of Inertia," &c., I had occasion to adduce for consideration a problem to the following effect :—

Relatively to a reference-frame which may itself have any motion whatever (but which is to be regarded as unknown or as disallowed for any use in observation or measurement), a set of points are known to have motions which are rectilinear and mutually proportional in simultaneous progress. From observations or measurements on successive simultaneous configurations of the set of points merely, to find a reference-frame relatively to which their motions will have that same character.

On the suggestion of this problem for solution being made to Prof. Tait, on the evening of the meeting already referred to, he

promptly replied that he could solve it very briefly by quaternions. (See *ante*, page 575, footnote.) I myself soon after succeeded in devising a solution, and my object in the present paper is to offer that solution to the Society. Prof. Tait too, I trust will submit his quaternion solution this evening to the Society.

Let us take the case of three points moving rectilinearly and mutuo-proportionally relatively to a frame. Three points are enough, but we might use more, and might so bring out varied solutions; and besides it may be mentioned here that a distinction of importance will be found to exist between the results attainable for three points only, and for a greater number than three. This will be referred to at a later stage (near the end of the paper, pages 740 and 741).

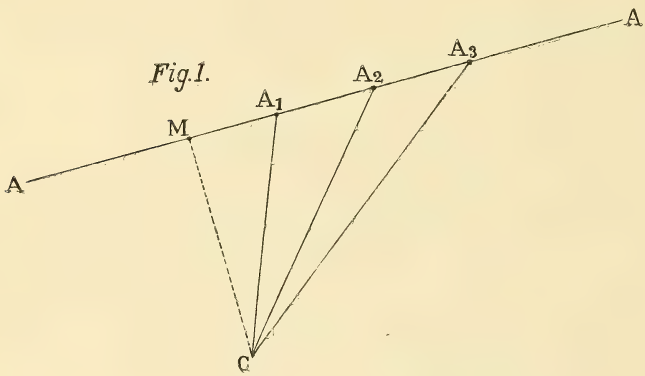
Let these three points to be used be called in general A, B, and C, irrespectively of changes in their mutual configuration, or in their situations relative to any frame. Let us proceed to find a frame relatively to which any one of these three points, say the point C, shall be at rest, and the other two shall move rectilinearly and mutuo-proportionally. Let successive simultaneous situations of A and B at instants of measurements be designated as A_1 and B_1, A_2 and B_2, A_3 and B_3, &c. We may thus bring into consideration and into use a set of portable triangles A_1CB_1, A_2CB_2, A_3CB_3, and more if wanted, representing severally in forms and dimensions the likewise designated original triangles; or, it may be, representing the originals in form, while constructed on any convenient scale of dimensions. The use of such altered scale is to be understood as available if the full original sizes would be inconvenient for use in a kinematical diagram, or mechanism, soon to be explained for construction or ideal contemplation. After this mere mention of allowable change of scale, the explanations will generally be given, for brevity and simplicity, as if the lengths of lines in the diagram, model, or mechanism, were identical with those of the corresponding original lines, rather than on an altered scale. We may denominate these several portable triangls in succession as templet 1, templet 2, &c.

Let us place the corners C of the three templets together, and take any plane passing through C, and bring the three lines CA_1, CA_2, CA_3, into that plane. Then take a straight line to be called

AA, movable in that plane; and, by motions of the lines CA_1, CA_2, CA_3, together with the motion of the line AA itself if necessary, bring the templet points A_1, A_2, A_3, into the line AA. Keep, until further notice, the line AA at a constant distance from C. This last bondage temporarily applied (that of keeping AA at a constant distance from C) is introduced merely as an aid in the reckoning of freedoms, and of their successive abolitions. It is not essential, and for some possible varied modes of thought it may well be omitted.

The figure here illustrates the arrangement so effected. It is to

Fig. 1.



be understood that we are to suppose ourselves free from any doubt as to whether, at the instant of any measurement, the moving point A or B, as the case may be, is diminishing or increasing its distance from C; for instance, we are to suppose that we are fully aware at which side of M in the line AA we are to place the point A_1; the the line CM being the line of shortest distance from C to AA.

Next take another straight line to be denominated as BB, and place it passing through B_1 and B_2 wherever these templet points may happen to be. Then rotate templet A_3CB_3 round its side CA_3 till its side CB_3, regarded as an interminate straight line, comes to meet the line BB which itself is movable, and may, if necessary or desirable, be shifted while retaining the points B_1 and B_2 in it. This operation may be stated in other words as being the operation of bringing the templet line CB_3 into the plane of B_1 and B_2 and C, or, what is the same, into the plane of the point C and the line BB

holding in it the points B_1 and B_2. Now, in general, on the accomplishment of this, we shall have the three points B_1, B_2, and B_3, not in one straight line, though all in the plane of B_1, B_2, and C. That is to say, the line B_1B_2 will cut the interminate line CB_3, but generally not in its point B_3. But now, rotate templet 1 round CA_1 or templet 2 round CA_2 till B_3 kept in the plane B_1CB_2 comes into the interminate straight line B_1B_2, or, what is the same, into the line BB. So now we have attained to the following state of things, *videlicet*:—

Firstly. Line AA is kept at an unchangeable distance from the point C.

Secondly. Three templet points A_1, A_2, A_3, are kept in the straight line AA; and three other templet points B_1, B_2, B_3, are all situated in one straight line BB.

Under these conditions, without departing from them, and while considering the point C and the line AA, and consequently CA_1, CA_2, CA_3, as being all at rest, we can move any one of the three templets by rotation round its line CA; and the other two will be bound to move with that one, and to assume fixed places when that one is fixed;—or, in other words, motion or rest of all the three is exactly decided by motion or rest of any one templet.

Two Varied Methods for Continuation.

Having arrived at this stage, we may go forward to accomplish a solution by either of two branch methods which will be stated now successively.

Method I.—The state of things already arrived at being maintained, if now further we introduce one more templet A_4CB_4, placing its point C to coincide with the C of the previous templets, and bringing its point A_4 into the line AA; and if we rotate this new templet round the fixed side CA_4 as an axis, and move also, if we please, or if necessary, the line BB in the freedom it has, and carry on either or both of such motions till we get the interminate line CB_4 to meet the interminate line BB (that is, in other words, till we get CB_4 into the plane of C and BB) the point B_4 will not in general find itself in the line BB (but BB will meet some point of CB_4 other than B_4). Let us, however, while maintaining the arrangements or conditions already arrived at, shift the line BB in

the freedom it possesses till B_4 comes into that line BB, and then let us make that conjuncture binding for the future.

Now all will be clamped or locked completely during our maintenance of the temporarily employed condition of AA being kept at an unchanging distance from C.

Next release that condition and shift AA to any new distance from C, and it will follow that BB will be fixed in a new situation; and, for AA moving, BB will be bound to an exact movement accordingly.

But now introduce one more of the templets, templet A_5CB_5, with its point A_5 brought into the line AA and kept bound to remain in that line, and with its line CB_5 brought into the plane of C and BB. This being done, the point B_5 will generally not find itself in the line BB; but we can shift AA towards or from C, moving consequently the plane CBB and the line BB in that plane till the line BB gets B_5 entered into it.

Thus all is completely clamped; and the two straight lines of motion of the points A and B relative to the desired frame in which C is at rest, are found relative to each one of the configurations ABC at the successive instants of the measurements. But those *past* configurations of the points A, B, and C, are already lost to us; and so we must proceed to find the lines AA and BB relative to one or more future configurations of those three points which are the only things that are to be available to us to make measurements from. It is here to be distinctly noticed that the lines of motions AA and BB, being fixtures in the desired frame, may perfectly well be accepted as constituting that frame; or even *one* of them along with the point C (which is also a fixture in the desired frame) might equally well be accepted as constituting the desired frame.

Now we have to observe that, from the nature of the data, and of the operations performed in the kinematical model or mechanism, and result arrived at in it, it must be the case that the lengths A_1A_2, A_2A_3, A_3A_4 &c., and B_1B_2, B_2B_3, B_3B_4, &c., found in the model as reprrsentatives of simultaneous travels of the real points A and B relative to the desired frame, must be mutually proportional. Hence, by continuing forward for the future a like proportional division along BB for any arbitrarily marked graduation along AA, we can by measurements from the model foretell future

instantaneous configurations of the points A, B, and C, and the situations of the fixed lines of motion AA and BB relative to those future configurations. So at any future instant when one of those prophesied configurations arrives, we shall have the means of specifying relative thereto the lines AA and BB; and these, as already explained, are to be accepted as the desired frame; that is, as being a frame accomplishing all the requisites of the problem.

METHOD II.—Reverting now to the stage arrived at just before our commencement of branching out into the two varied methods, and maintaining the state of things there attained to, we may proceed by a second alternative method as follows:—It is to be recollected that, in the state of things attained to, we have three templet points A_1, A_2, A_3, all in one straight line AA; and three other templet points B_1, B_2, B_3, all situated in another straight line BB; and that, while keeping the line AA at a changeless distance from the point C, and regarding the line AA and the point C as being at rest, and consequently regarding the points A_1, A_2, A_3, as being also all at rest, we can keep moving the line BB, in the one freedom it possesses, and so we can alter continuously the distances B_1B_2 and B_1B_3, and we may readily further see that we can alter continuously the ratio of either of these distances to the other. So let us ordain the requirement that we are thus to keep moving the line BB in the freedom it possesses till we attain the condition that:—

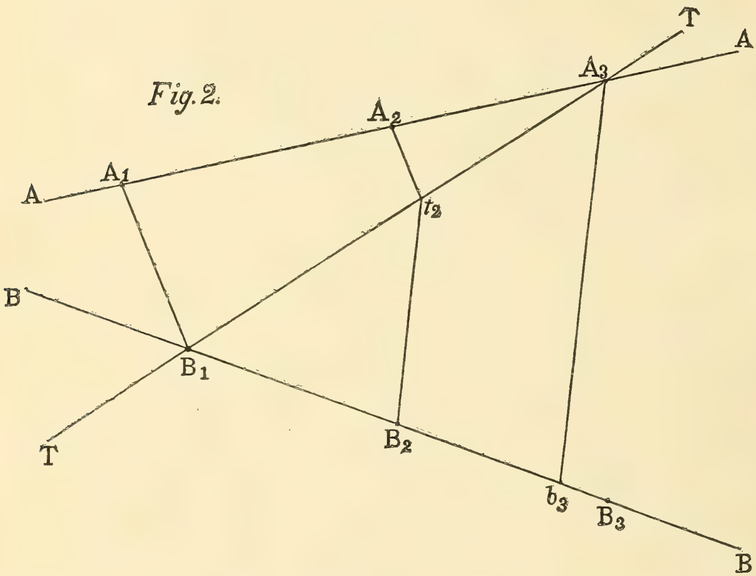
$$\text{As } A_1A_2 : B_1B_2 :: A_1A_3 : B_1B_3 .$$

For the purpose of accomplishing this requirement we may use (ideally at least) a mechanism of parallel rulers or parallel projectors, &c., which will now be briefly described. For guidance in geometrical principles towards formation of the conceptions intended, imagine a straight line placed intersecting the lines AA and BB. Let us name this line as the transversal, or refer to it as the line TT. Imagine the points A_1, A_2, A_3, to be projected to the transversal by parallel projectors; and imagine the points so found on the transversal to be further projected to the line BB. Call the points so found on BB, the points b_1, b_2, b_3, in correspondence with A_1, A_2, A_3, from which they have been respectively derived Now obviously we have by geometry,

$$A_1A_2 : b_1b_2 :: A_1A_3 : b_1b_3 .$$

Further it may easily be seen that we can gradually change the directions (or clinures) of the two sets of parallel projectors until we get the point b_1 to coincide with B_1, and maintaining that coincidence we can go on changing the directions of both sets of parallel projectors till we get also b_2 to coincide with B_2. This being done we can, by observing whether or not b_3 coincides with B_3 ascertain whether or not it be the case that $A_1A_2 : B_1B_2 :: A_1A_3 : B_1B_3$. The general principle thus indicated can be applied to the case immediately before us in a simplified combination by choosing to make the transversal pass through the points A_3 and B_1 as in fig. 2, where TT represents the transversal. The figure

Fig. 2.



is to be understood as being a pictorial representation on the paper, of lines and points not themselves situated in the plane of the paper, and not all existing in any one plane. Then take a pair of straight lines kept parallel by mechanism (as for instance is the case in some commonly used kinds of parallel rulers) and place one of these lines so as to pass through A_1 and B_1 and make the other pass through A_2. This second line being parallel to A_1B_1 (see fig. 2) must be in a plane with it and with the line AA and consequently with the transversal. So it meets the transversal.

These two parallel lines are represented in the figure as A_1B_1 and $A_2\,t_2$. So now we have, in the figure,

$$A_1A_2 : B_1t_2 :: A_1A_3 : B_1A_3 .$$

Take two other straight lines kept parallel by mechanism, and place one of them across from t_2 to B_2 and make the other pass through A_3, and then it will necessarily meet the line BB. So these two parallel lines will be represented in the figure as t_2B_2 and A_3b_3; and we shall have :—

$$A_1A_2 : B_1B_2 :: A_1A_3 : B_1b_3 .$$

Now in general it will result that b_3 so found will not coincide with B_3; but let us now keep the line BB moving in the freedom it possesses, and keep the two pairs of parallel lines maintaining the conditions to which they have been set, and continue the motion until the points b_3 and B_3 come to coincide, and bind these two points to remain together; or, in other words, bind the line A_3b_3, when brought to pass through the point B_3 hitherto movable along the line BB, to continue holding the templet point B_3. Thus all will be clamped as long as the temporarily imposed condition of changeless distance from the templet point C to AA is maintained.

But if now we change that distance, and fix on a new changeless distance instead, while maintaining all the conditions already attained to, the whole system will take up a new configuration and will become clamped therein.

Or we might express this by saying :—Fix AA at an altered distance from C, and by going through the same process as before we get one fixed configuration for the whole system. So if we relax the condition of changeless distance of AA from C, the whole system has one and only one freedom.

For the next step we do not require another complete templet. We may use merely the lengths CA_4 and CB_4 got by measurement. That is let us have a portable triangle with two sides CA_4 and CB_4 given, but the angle between them left unknown, and that, for our present operations, is the same as to say :—left variable. Put the vertex C, or joint C, of that portable triangle at the point C of our model. Bring CA_4 into the plane CAA, and swing it round till A_4 comes into the line AA. Also put the rod or bar CB_4 into the

plane CBB; and swing it round till B_4 comes into the line BB. This being done, the proportionality wanted,

$$\text{that} \quad A_1A_2 : B_1B_2 :: A_1A_4 : B_1B_4$$

will generally *not* have been instituted. But now, while maintaining all the conditions already attained to, move AA varying its distance from C, till that proportionality takes place as indicated by the mechanism of parallel rulers, &c., already used, but with some obviously necessary additions sufficiently suggested by the explanations already given. Now the whole system becomes clamped, and the problem is solved, or the rest is easy as in Method I., the two straight lines AA and BB, being lines fixed in the sought-for frame, and it being possible to find them for any prophesied future configuration of the set of three points A, B, and C, as has been explained at the close of the explanations for Method I.

It becomes now convenient and desirable to examine into some questions as to how many distinct elements of data from measurement, or how many ascertained conditions from measurement, are required for the solution of the problem; and as to whether there are more essentially distinct solutions than one in various cases of the number of points used and the number of conditions from measurement ascertained.

It is to be recollected, as was pointed out near the end of the explanation of Method I. that the lengths A_1A_2, A_2A_3, A_3A_4, &c., and B_1B_2, B_2B_3, B_3B_4, &c., found in the model as representatives of simultaneous travels of the real points A and B relative to the desired frame, must be mutually proportional. But the conditions of this mutual proportionality have been left unused in the solution, and so we may see that in Method I. we have used redundant data. It is to be understood that the introduction of any one complete templet brings in just *two* not *three* new conditions. Though for it there are three sides measured, yet the only conditions thereby ascertained are that when some one side has a certain stated length, a second side has another ascertained length, which is one condition, and that also at the same instant the third side has another ascertained length which is another condition; and this makes with the previous one only *two* in all.

In Method I. after the stage up to which the procedure is

common to both Methods I. and II.; we have—(a) templet 4 introduced involving two additional conditions from measurement, and (b) templet 5 introduced, involving two additional conditions from measurement. So in respect to these two templets 4 and 5 we have four conditions introduced.

And in the whole of Method I. there are the following known conditions unused:—

$$\left.\begin{array}{ll}\text{That} & \dfrac{B_1B_2}{A_1A_2}=\dfrac{B_1B_3}{A_1A_3} \\[2ex] \text{that} & \dfrac{B_1B_2}{A_1A_2}=\dfrac{B_1B_4}{A_1A_4} \\[2ex] \text{and that} & \dfrac{B_1B_2}{A_1A_2}=\dfrac{B_1B_5}{A_1A_5}\end{array}\right\}$$

That is, in all, three known conditions unused. So instead of ascertaining 4 conditions by measurement and neglecting 3, we might get the result by $4-3$, that is one new condition from measurement. Now in Method II. we do demand from measurement just one new condition, and we have no redundant information. The one new condition so introduced is the condition brought into use by the incomplete templet 4; *videlicet*, that when CA has a certain stated length CB has another certain ascertained length.

So, on the whole, in Method I. we have from measurement 5 templets supplying two conditions each, that is, we have 10 conditions from measurement; and, as shown already, we are thus supplied with 3 redundant conditions; and so $10-3$ or 7 conditions from measurement, or independent data, must somehow be enough.

Passing to Method II. we see that in it we have 3 complete templets supplying 6 conditions, and 1 incomplete templet supplying 1 condition; and we have got no redundant conditions; but we have just 7 conditions found necessary and brought into use.

So the two methods agree in showing that the number of independent conditions from measurement necessary to be supplied is *seven.*

There is yet a curious matter which I have to adduce for consideration. Many matters of interest may indeed remain for further consideration or for mathematical investigation in connection with this subject; but I do not at all profess to exhaust the subject, and I shall only be glad if it be found that I escape from offering inadvertently any importantly erroneous views.

What I do propose now further to put forward is some scrutinies as to whether the problem entered on, in some of its varieties, admits of duplicate or multiple results for accomplishing its conditions; and to open out some views in relation to this matter which appear to be true and to be of interest.

It is to be noticed that when we begin putting together our templets for the kinematical model or mechanism for three original moving points A, B, and C, we have no means available for knowing on which side of templet 1 we are to place the point A_2 of our templet 2, and on which side of the same we are to place the point B_2 of our templet 2. Further, it is to be noticed that, under the restriction of our measurements being confined to three of the original points only, we have no means whatever for making the extra measurements, or taking the extra observations that would supply us with means for choosing one side rather than the other of templet 1, as that on which we ought to place either A_2 or B_2. To help our conceptions let us imagine among the original moving points a reference frame relative to which the original point C shall be at rest and which shall have no rotation relative to the original secret frame; and let us name this as the *vice-original frame* and designate it briefly by the letter Φ. Let us imagine the original triangular plane ACB as having one of its two faces red and the other blue; and imagine its face which at the point A is anterior in its motion relative to the vice-original frame to be red, and the one which at that point is posterior to be blue. In respect to this it is to be noticed that the red face thus specified though anterior at A may happen to be the posterior one at B: but this need not give us trouble, and for brevity we may speak of the red face which at A is anterior as being *the anterior face.* Let the faces of all the templet triangles be coloured red and blue correspondingly.

By going forward with considerations readily suggested by what has just been set forth, we may obviously find that the process of solv-

ing the stated problem for the case of only three original points by the kinematical mechanism can bring out two straight lines AA and BB really at rest relatively to the vice-original frame, and consequently having all their points either at rest or moving rectilinearly and mutuo-proportionally in relation to the original secret frame: and further that the same process of solving the stated problem can bring out another real true solution in finding two straight lines which we may call A′A′ and B′B′ which will be the images of AA and BB in a plane mirror whose plane always passes through the three points A, B, and C. The two straight lines A′A′, B′B′ so found may be taken as lines fixed in a frame which we may designate as Φ′, and which will rotate relatively to the vice-original frame Φ, as also relatively to the original secret frame. Now, as the motion of the original points goes on making their distances apart increase unlimitedly, this relative rotation between the frames Φ′ and Φ will be becoming evanescent, and the two frames will be approaching unlimitedly towards relative rest. So the solution which brings out the frame Φ′ approaches ultimately to identification with that which brings out the frame Φ which is in agreement with the original secret frame.

If now instead of using the three points C, A, and B, we use a different group of three points C, A, and D, these will bring out for us as solutions two frames Φ and Φ″, of which the one Φ will be identical with the frame Φ already found by the three points C, A, and B. It follows from this (and it seems very obvious that it could be brought out in various other ways), that for four original points no frame in general could be brought out as a solution except one in agreement with the original secret frame; that is to say, a frame either at rest relatively to that original frame, or having all its points moving rectilinearly and mutuo-proportionally relatively to that original frame. One reason which seems very decisive in favour of this conclusion is:—that if any three of all the original points be retaining their distances apart unchanging, then these three will themselves constitute a frame Φ which will be in agreement with the original secret frame: and then for any other one or more of the original points taken along with these three, no frame will be possible to serve as a solution except such as shall be in agreement with that one.

Postscript.

The ideas noted in what follows had not completely occurred to me till after the evening of the meeting of the Society when the paper was read, and a suggestion towards their development came from Professor Tait's paper of the same evening "On Reference Frames." Thus it seems suitable to annex them here as a postscript.

It may be noticed that in the case referred to in the last sentence of the paper just before this postscript—the case of three original moving points retaining their distances apart unchanging—the method of procedure employed throughout the paper would collapse because the points A and B would be at rest relatively to the vice-original frame, and so the straight lines of motion AA and BB previously used would become only two points. Yet a solution is in this case even more readily available than in the previously considered cases. It thus becomes desirable to find some way of harmonising the two modes of thought or of procedure so as to bring them into connection; rather than to be content to suppose that, in passing from one to the other, we should have quite to abandon the one mode of thought, and take up another and quite unallied mode instead.

A satisfactory connection between the two presents itself, if, instead of taking from the kinematic model only the lines of motion AA and BB, as the basis for our desired frame, we take from that model also the points A_1 and B_1 on those lines, getting them known by measurement of their distances from any future points A_n and B_n, so that when, among the three original points A, B, and C, the particular configuration A_nCB_n found in anticipation from the model shall come to exist, the old triangular frame A_1CB_1 shall become known to us relatively to the then existing frame A_nCB_n. In this way of procedure, the solution, for the case of A and B being, as well as C, at rest in the vice-original frame, will come out simply by the distances A_nA_1 and B_nB_1 being each zero in length, and by the concomitant of this, that the old frame A_1CB_1 is to be found as being coincident with the new momentarily existing and known frame A_nCB_n.

2. Note on Reference Frames. By Professor Tait.

As I understand Prof. J. Thomson's problem (*anté*, p. 568) it is equivalent to the following :—

A set of points move, Galilei-wise, with reference to a system of co-ordinate axes; which may, itself, have any motion whatever. From observations of the *relative* positions of the points, merely, to find such co-ordinate axes.

It is obvious that there is an infinitely infinite number of possible solutions; because, if one origin moves Galilei-wise with respect to another, and the axes drawn from the two origins have no *relative* rotation, any point moving Galilei-wise with respect to either set of axes will necessarily move Galilei-wise with respect to the other. Hence any one solution suffices, for all the others can be deduced from it by the above consideration.

Referred to any one set of axes which satisfy the conditions, the positions of the points are, at time t, given by the vectors

$$\alpha_1 + \beta_1 t \text{ for A}, \quad \alpha_2 + \beta_2 t \text{ for B}, \text{ \&c., \&c.}$$

But it is clear, from what is stated above, that we may look on the pair of vectors for any *one* of the points, say α_1 and β_1 for A, as being absolutely arbitrary :—though, of course, *constant*. We will, therefore, make each of them vanish. This amounts to taking A as the origin of the co-ordinate system. The other expressions, above, will then represent the relative positions of B, C, &c., with regard to A.

The observer on A is supposed to be able to measure, at any moment, the lengths AB, AC, AD, &c.; the angles BAC, BAD, CAD, &c.; and also to be able to recognise whether a triangle, such as BCD, is gone round positively or negatively when its corners are passed through in the order named. What this leaves undetermined, at any particular instant, is merely the absolute direction of *any one line* (as AB), and the aspect of *any one plane* (as ABC) passing through that line. These being assumed at random, the simultaneous positions of all the points can be constructed from the permissible observations. But it is interesting to inquire how many observations are necessary; and how the βs depend on the αs.

Thus, at time t, whatever be the mode of measurement of time, we have equations such as follows:—

$$-a = \alpha_2^2 + 2S\alpha_2\beta_2 \,.\, t + \beta_2^2 t^2,$$
$$-b = S\alpha_2\alpha_3 + S(\alpha_2\beta_3 + \beta_2\alpha_3) \,.\, t + S\beta_2\beta_3 \,.\, t^2,$$
$$-c = \alpha_3^2 + 2S\alpha_3\beta_3 \,.\, t + \beta_3^2 t^2,$$
$$\ldots = \ldots\ldots\ldots\ldots$$

For any one value of t we have n equations of each of the 1st and 3rd of these types, and $n(n-1)/2$ of the 2nd, $n+1$ being the whole number of points. In all, $n(n+1)/2$ equations.

The scalar unknowns involved in these equations are (1) the values of t; (2) α_2^2, α_3^2, &c.; (3) β_2^2, β_3^2, &c.; (4) $S\alpha_2\alpha_3$, &c.; (5) $S\beta_2\beta_3$, &c.; (6) $S\alpha_2\beta_2$, $S\alpha_3\beta_3$, &c.; and (7) $S(\alpha_2\beta_3 + \beta_2\alpha_3)$, &c. Their numbers are, for (2), (3), (6), n each; for (4), (5), (7), $n(n-1)/2$ each; in all $3n(n+1)2$. Suppose that observations are made on m successive occasions. Since our origin, and our unit, of time are alike arbitrary, we may put $t=0$ for the first observation, and merge the value of t at the second observation in the tensors of β_2, β_3, &c. This amounts to taking the interval between the first two sets of observations as unit of time. Thus the unknowns of the form (1) are $m-2$ in number. There are therefore

$mn(n+1)/2$ equations and $3n(n+1)/2 + m - 2$ unknowns.

Thus $m=3$ gives an insufficient amount of information, but $m=4$ gives a superfluity.

In particular, if there be three points only, which is in general sufficient, 3 complete observations give

9 equations with 10 unknowns;

while 4 complete observations give

12 equations with 11 unknowns.

Thus we need take only two of the three possible measurements, at the fourth instant of observation.

The solution of the equations, supposed to be effected, gives us among other things, α_2^2, α_3^2, and $S\alpha_2\alpha_3$. *Any* direction may be assumed for α_2, and *any* plane as that of α_2 and α_3. Fom these assumptions, and the three numerical quantities just named, the co-ordinate system required can be at once deduced.

This solution fails if $(S\alpha_2\alpha_3)^2 = \alpha_2^2\alpha_3^2$, or $TV\alpha_2\alpha_3 = 0$; for then the three points A,B,C, are in one line at starting. But this, and similar cases of failure (when they *are* really cases of failure) are due to an improper selection of three of the points. We need not further discuss them.

But it is interesting to consider how the vectors β can be found when one position of the reference frame has been obtained. Keeping, for simplicity, to the system of three points, we have by the solution of the equations above the following data:—

$$S\alpha_2\beta_2 = e,\ S\alpha_3\beta_3 = e',\ S(\alpha_2\beta_3 + \beta_2\alpha_3) = f,\ T\beta_2 = g,\ T\beta_3 = g',\ S\beta_2\beta_3 = h;$$

where e, e', f, g, g', h are known numbers; which, as the equations from which they were derived were not linear, have in general more than one system of values. The second, third, and sixth of these equations give

$$\beta_3 S . \alpha_2\alpha_3\beta_2 = hV\alpha_2\alpha_3 + (f - S\beta_2\alpha_3)V\alpha_3\beta_2 + e'V\beta_2\alpha_2 .$$

Provided β_2 is not coplanar with α_2, α_3, this equation gives, by the help of the fifth above, a surface of the 4th order of which β_2 is a vector. But β_2 is also a vector of the plane $S\alpha_2\beta_2 = e$, and of the sphere $T\beta_2 = g$. Hence it is determined by the intersections of those three surfaces.

But if $S . \alpha_2\alpha_3\beta_2$ vanishes, the equation above gives (by operating with $S . V\alpha_2\alpha_3$)

$$0 = h(V\alpha_2\alpha_3)^2 - (f - S\beta_2\alpha_3)S . \beta_2 V . \alpha_3 V\alpha_2\alpha_3 + e'S . \beta_2 V . \alpha_2 V\alpha_2\alpha_3 ,$$

which gives a surface of the second order (a hyperbolic cylinder) in place of the surface of the fourth order above mentioned. This may, however, be dispensed with:—for β_2 is in this case determined by the planes $S\alpha_2\beta_2 = e$ and $S . \alpha_2\alpha_3\beta_2 = 0$, together with the sphere $T\beta_2 = g$.

3. Note on the Occurrence of Drifted Trees in Beds of Sand and Gravel at Musselburgh. By James Geikie, LL.D., F.R.S.

I am indebted to Mr William Robertson for calling my attention to the interesting phenomena which form the subject of this

communication. Some months ago he showed me at his works, Haymarket, the trunk of a large oak which had been obtained from beds of sand and gravel in his property at Olive Bank, Musselburgh. The wood was very dark in colour, and in a fine state of preservation. It was, in fact, in process of being sawn into planks, from which a number of useful and ornamental articles have since been made. The trunk was perfectly straight, showing no appearance of branches, and when first uncovered measured 31 feet in length, having a diameter of 2 feet at the butt end close to the roots, from which it tapered upwards very gradually. The portion seen by me in Mr Robertson's premises had been more or less scraped by his workmen, and the bark was almost entirely wanting; but I was informed that very little bark appeared when the tree was disinterred. The roots were somewhat rounded, and looked as if they had been rubbed and abraded. Shortly afterwards I visited the sand-pit, and saw the trunk of another large oak *in situ*. It was only partially uncovered, the portion concealed being buried under some 10 feet of sand and gravel. The trunk was hollow and filled with wet sand, and the wood was so soft that it could be cut in most places with a spade. The greatest diameter of the exposed portion was 3 feet 9 inches, and when the trunk was finally dug out it was found to measure 18 feet in length. But Mr Robertson informs me that, before the time of my first visit to the sand-pit, the workmen had dug away a considerable portion of the dark brown soft woody matter, under the impression that this was merely "peat," and he estimates the length of the part so removed as not less than 30 feet, and thinks the trunk at its butt end could not be less than 5 feet in diameter. This would give a total length for the trunk of 48 feet. It was not so straight as No. 1 tree, and unlike it, it had several branches. Most of the bark had been removed from the tree before the time of its entombment, but some still adhered in places, and was covered with a foliaceous lichen. Here and there also the trunk was thickly set with the stems of a clinging or climbing plant, which may have been ivy. I did not, however, detect any leaves of that plant; but in the hollow of the trunk I picked out a few leaves of holly, and other vegetable matter which was too decayed to allow of identification. Since this tree was exposed, other two have been extracted. One of these

resembled No. 1 tree in the soundness of the wood, but the trunk was hardly so straight, and it had several branches. At 1 foot above the roots it measured 20 inches in diameter, from which it tapered upwards for 26 feet to a diameter of 1 foot, after which it bifurcated, the two branches measuring 16 feet 6 inches and 6 feet 6 inches respectively. There were smaller branches also both on the main trunk and on the two principal branches. The fourth tree I did not see *in situ*, but in Mr Robertson's premises. It measured 2 feet 7 inches in diameter near the root, but bifurcated at about 4 feet 6 inches. Only one of the two limbs, however, remains, and it measures 18 feet 4 inches in length. It also bifurcates, the branches measuring 18 feet and 15 feet, with diameters of 9 inches and 7 inches respectively.

All the trees were more or less soft and spongy externally, the soft wood being readily removed by a spade to the depth of an inch or more. They seem to have been for the most part deprived of their bark before they became buried in the sand, and the worn and abraded character of the roots and branches was just such as we see in trees which have been drifted some distance in water. It remains only to add that the trees were lying with their butt ends directed inland. Nos. 1 and 4 I did not see *in situ*, but the others I took the direction of, and found that the top of No. 2 pointed E. 20 N.; and Mr Robertson informed me that No. 1 had the same direction. No. 3 tree lay N. 5 W. or nearly north and south, the top being directed seawards. No. 4, again, appears to have had very much the same direction, the top being directed a few degrees more to west of north. I may add, that the four trees now referred to occurred within a dozen yards or so of each other, one of the branches of the great hollow trunk (No. 2) lying across No. 3 tree. Scattered through the sand in the neighbourhood of the trees, many twigs and branches were seen, some of which may have belonged to those particular trees; it is quite possible, however, that a portion of the vegetable débris may have become entangled in the roots and branches of the snags as it drifted seawards.

The succession of deposits seen in the sand-pit is in descending series, as follows (see fig. 1):—

(*a*) Soil, &c.

(*b*) Sand, white and yellow, about 1 foot 6 inches.

(*c*) Peat, about 9 or 10 inches.

(*d*) Gravel and Sand, excavated to a depth of 8 or 9 feet.

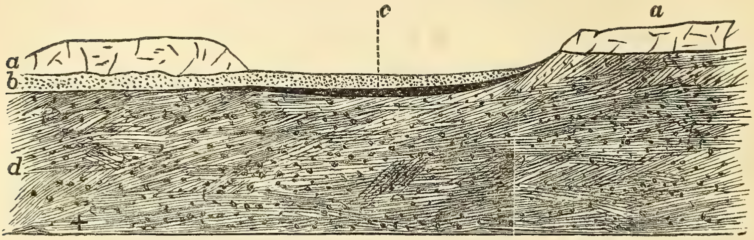


Fig. 1. Section in Sand Pit, Olive Bank, Musselburgh. *a*, Soil, &c.; *b*, sand; *c*, peat; *d*, sand and gravel. + Position of drifted trees.

The Sand (*a*) is a moderately fine-grained siliceous sand, seen only in the north part of the sand-pit. It dies out rapidly to the south. The granules are often coated with hydrous ferric oxide, and the bed becomes quite ochreous towards the north. No fossils seem to occur. The bed is overlaid by a mass of "made ground," consisting of sandy soil, in which fragments of very recent pottery and glass are seen.

The thin bed of peat underlying this sand is in like manner restricted to the north end of the pit. It occupies a hollow, and dies out rapidly to north and south. Both it and the overlying sand abut against the subjacent gravel and sand in such a way as to show that the latter had been considerably denuded before the accumulation of the peat and upper sand-bed had commenced. There is nothing particularly noteworthy about this peat, save that it seems to be made up to a considerable extent of the remains of trees, such as birch, elm, Scots fir, &c. Here and there I detected the wing-cases of beetles, and possibly other organic remains may occur, for I made no special search. Both this peat and the overlying sand-bed are evidently of much more recent date than the gravel and sand below, and it is to these specially that attention is at present directed.

The deposits in question have been excavated to a depth of 8 or 9 feet, and how much thicker they may be I cannot say, but the boulder-clay will probably be met with at no great distance from the bottom of the sand-pit; and possibly the sand and gravel do not attain a greater thickness than 20 or 30 feet. The beds

exposed in section are somewhat variable, and show a good deal of diagonal bedding, pointing to somewhat persistent current action from the south; in a few places, however, there is evidence of a movement in quite the opposite direction. Although the deposits show so much false-bedding, the inclination of all the various lenticular beds and sheets of gravel and sand is towards the north at a low angle, between 2° and 3°. The sand is chiefly siliceous, and remarkably "sharp" or clean, and it greatly predominates over the gravel. Some layers are very fine, others are less so, passing into a grit. The gravel consists of well water-worn stones, varying in size from mere grit up to fragments several inches in diameter. Coarser and finer gravels alternate in lenticular or irregular layers and beds, which interosculate with lines and sheets of sand. So far as I have observed, there are no rock-fragments in the gravel which do not also occur in the boulder-clay of the same district, and very few, if any, that might not have been derived from the drainage-area of the River Esk, which enters the sea about half a mile to the east of our section.

It is in these gravel and sand beds that the drifted trees occur. They were met with at or about the bottom of the section in the sand-pit, and all within a distance of 40 feet of each other. The absence of any trace of marine organisms in the beds, taken in connection with the presence of the drifted trees, branches, twigs, &c., suggests the fluviatile origin of the deposits, and the same might be inferred from the general appearance of the deposits themselves. All the evidence points to a flow of water from south to north. The inclination of the various layers, the "pitch" of the diagonal bedding, the shape of the gravel stones (well water-worn, but not generally so well rounded as marine gravel), the manner in which the stones often overlap, and the general disposition of the materials precisely resemble what we see in the recent alluvial accumulations of our larger rivers, and in certain older valley-terraces laid down by many of our streams at a time when these flowed in greater volume than at present. The deposits at Musselburgh occur some 30 feet above Ordnance datum-line, and form part of a broad terrace which slopes gradually inland to a height of as near as may be 45 feet. Indeed, the 50 feet contour line may be taken as the boundary of the gravel and sand, the terrace formed by which

abuts against a well-defined bank of boulder-clay. This bank and terrace may be followed more or less clearly from the site of St Mary Magdalene's Chapel near Pinkie Salt Pans, south-east by the municipal boundary and Stoneyhill to Stoneypark, where they are

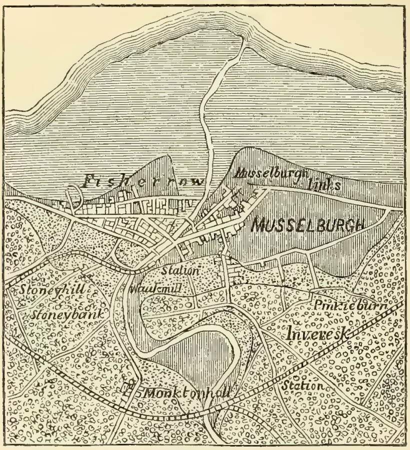


Fig. 2.

truncated by the modern "cut" of the Esk (see fig. 2). At Monktonhall they again come on, forming well-marked features—the terrace sloping gradually down to the more recent alluvium of the Shire Haugh opposite Inveresk. The counterparts of this sloping bank and broad terrace are also met with on the east side of the Esk. Thus, they are well seen between the river and Inveresk, from which they may be followed down to a little beyond the Waukmill, after which the bank sweeps away to the east by Inveresk House and Pinkiehill Colliery, until eventually it turns north by Pinkie Brae, and is at last truncated by the 25 to 30 feet beach to the east of

Fig. 3. Section across superficial Deposits at Musselburgh. 1, Glacial Deposits ; 2, 45–50 feet terrace ; 3, 25 feet terrace ; 4, sea.

Musselburgh Links. It may be added that this last-named beach has been excavated in our old terrace, across its whole breadth from west to east, so that in descending seawards from the bank which forms the margin of the 45 to 50 terrace, we first traverse

that terrace, and then reach the short slope or bank that overlooks the 25 feet beach and the modern alluvia (see fig. 3). And just as the deposits of the 25 feet beach pass up the valley of the Esk into well-marked haughs of river alluvia, which gradually ascend with the slope of the valley; so, when we follow the deposits of the older terrace inland we find them in like manner rising to a gradually higher level, and behaving in every respect like ordinary river alluvia. There cannot, therefore, be any doubt, I believe, that the sand and gravel which contain the drifted trees are of fluviatile origin —accumulations formed by the Esk, at a time when that river flowed at a higher level and in considerably greater volume than at present.

Since the upper or 45–50 feet terrace was formed the River Esk has cut its way down through that terrace and the boulder-clay and carboniferous strata to a depth of some 30 feet; and the greater size of the Esk when flowing at the 45–50 feet level is indicated not only by the character and bulk of the deposits then laid down but by the much wider area over which these extend. I think it is also suggested by the great size of the drifted trees, which could hardly have been floated seawards by such a stream as the modern river.

It is of some interest now to inquire what relation this ancient alluvial terrace bears to the raised beaches which occur at so many different places on both sides of the Firth of Forth. From what I have seen of those old sea-beaches I have little doubt that the tree-bearing beds referred to in this communication are on approximately the same geological horizon as the well-known 45–50 feet beach; that, in short, the sand and gravel in which the great trees occur were deposited at or near the mouth of the Esk, when the sea-level stood some 45 feet higher than it now does. This appears to be shown by the fact that the upper limit of the terrace at Musselburgh preserves the same level when followed from west to east across the valley of the Esk, and hardly begins to show any rise when traced up that valley until we reach Inveresk. In short, the deposits at Musselburgh seem to me to resemble the delta accumulations of a very considerable river, and it is just possible that some of the current-bedding seen in the sand-pit at Olive Bank may be the result of tidal action. But the body of fresh water flowing seaward would be sufficiently great to prevent the incursion

of marine organisms, and the absence of any trace of these is no proof that the land may not then have stood, relatively to the sea, some 45 or 50 feet lower than it does at present.

It is in the upper reaches of the Firth of Forth that the 45–50 feet beach is best developed. In the neighbourhood of Falkirk and Stirling the deposits of this level form the well-known Carse-lands—extensive sheets of mud, silt, clay, and sand, containing in many places recent sea-shells, such as *Cardium edule, Ostrea edulis, Cyprina islandica, Littorina litorea, Trophon clathratus, Buccinum undatum*, &c. The upper limits of this great flat are well marked out by bluffs and banks—the old coast-lines. Of its marine origin, therefore, there can be no doubt. Now, throughout the Carse-deposits there occurs at various levels much drifted vegetable débris, consisting of the trunks, branches, and twigs of such trees as birch, hazel, pine, and oak, and associated with these oyster-shells often appear in abundance. Remains of the whale,* dug-out canoes, and rude implements and weapons have likewise been discovered in the same deposits, while along what was the old shore-line kitchen-middens are frequently met with. All the middens, as Mr Peach observes, "occur on the bluff itself or just at its base, as if when it was the limit of high-water, the people who formed the middens, after searching the shores during low-water, had retreated thither to enjoy their feast while the tide covered their hunting-ground." It is noteworthy that when those Carse-deposits are followed up the valley, they are found rising with a gentle gradient, until eventually they pass into fresh-water alluvial deposits of sand and gravel of fluviatile origin. Here, then, at the head of the Firth of Forth, we meet with the counterparts of the Musselburgh beds. The evidence shows that at a time when the sea washed the 45–50 feet level the River Forth, flowing in much greater volume than at present, carried down to its estuary enormous quantities of drift-wood, some of which got bedded in the sand of the lower reaches of the river, some in the silt and mud of the estuary, while much no doubt found its way eventually out to the open sea. The Musselburgh

* Professor Turner informs me that the skeletons of large whales, which from time to time have been found embedded in the Carse-deposits of the Forth valley, so far as they have been critically examined, have been determined to belong to the genus *Balænoptera*, and are not examples of the *Balæna mysticetus*, or Greenland whale, as is generally believed.

beds, then, I take to be of the same age, and to betoken the same conditions, as are shown by the old fluviatile accumulations of the Forth at the point where these merge into the estuarine-marine beds of the Carse-lands.

It is remarkable that precisely the same phenomena are met with in the lower reaches of the Tay valley. In that district, however, the succession of changes evinced by the Carse-deposits and the correlative fluviatile accumulations of the Tay and Earn, is even more clearly read. In the Carse of Gowrie, for example, we detect underneath the clay of the Carse the remains of an ancient buried forest. The lower portions of the Carse-deposits are often abundantly charged with drifted vegetation, and here and there marine shells occur. I got oyster-shells and drifted wood in the Carse-beds a few years ago, during some excavations that were being made within the grounds of the Perth Penitentiary. But no marine remains have been met with higher up the valley, for as the deposits are traced further in that direction they pass gradually into fluviatile gravel and sand. That the Carse of Gowrie, &c., is of the same age as that of Falkirk, may be inferred from the fact that its upper limits reach the same elevation, viz., 45 feet. I may add that underlying the buried forest of the Tay and Earn valleys fluviatile gravel, sand, &c., are seen in some places. These phenomena, which I have described at length elsewhere,* seem to me to indicate the following succession of changes :—Taking first the fluviatile beds under the buried forest, these point to a time when the Tay flowed at a lower level than at present—for the old fluviatile beds referred to occur underneath the present mean tide-mark at and below Perth. Hence we may further assume that the land stood relatively to the sea somewhat higher then than it does now. Next in succession comes the buried forest. This, as I have shown, represents an old land surface which extends out seaward, and consequently proves that the Scottish shores formerly stretched much further to the east. I need not recapitulate the evidence which has led me to believe that the buried forest of the Tay valley finds its counterparts in the so-called submerged forests which are met with at many points along the shores of these islands and the opposite coasts of the Continent; and that the evidence furnished by these

* See *Prehistoric Europe*, p. 385.

leads to the conclusion that at the time those forests flourished, the British area formed a portion of the European Continent, and enjoyed a more genial climate than at present. The buried forest of the Tay is covered by the Carse-clays which are indubitably of estuarine or estuarine-marine formation. Consequently they show us that the continental conditions during which the great forests extended themselves had now passed away; more than this, we may infer from the appearances presented by the Carse-clays and correlative river deposits of the Tay and the Earn that the climate had now become less genial. The river-gravels referred to are more or less coarse tumultuous deposits extending over broad areas, and when they are followed into the Highlands they are actually found in close association with torrential débris and morainic accumulations. Again, the Carse-clays have all the appearance of those flood-loams and clays which are deposited by water flowing from snowfields and glaciers; and now and again they contain isolated stones and boulders which could only have been carried down to sea by river-ice. So that, at the time the clays of the Carse of Gowrie were accumulated, it would appear that local glaciers occupied some of the Highland glens, while our rivers had often a torrential character, and swept down to their estuaries immense quantities of fine silt, "the flour of rocks." Thus, as it seems to me, we have more or less distinct evidence in the Carse-deposits of the Tay and Earn of marked geographical and climatic changes.

Returning now to the Carse-accumulations of the Forth, we encounter very much the same appearances, but certain evidence is wanting. Thus we have not yet encountered any ancient buried forest underlying the Carse-clays of Falkirk and Stirling, which can be considered as the equivalent of the buried forest of the Tay valley. But we have every evidence to show that an arboreal vegetation similar to that which now forms our forests, clothed the hill-slopes and valley-bottoms in the region drained by the Forth, at the time the Carse-clays began to form. We have proof also of torrential and flooded rivers, and of the wholesale destruction of trees. No geologist who has studied the Carse-beds of the Forth can doubt that those accumulations occupy an old valley, the bottom of which is under the present level of the sea. Nor does it take much imagination to picture to one's self the conditions which must have

obtained in the Forth district at the time when the buried forest of the Tay stretched away out to sea. In place of the flats of the Stirling and Falkirk Carse and the waters of the estuary of the Forth, we see a broad and gently sloping valley clothed with thick forests, through which the ancient River Forth winds far away to the east, to mingle its waters in all probability with those of the Rhine, which at that time flowed northward through the area now covered by the North Sea. How long those conditions obtained we have no means of estimating, all one can say is that it was probably at or about that time that Neolithic man entered Britain. These geographical and climatic conditions eventually become changed. Britain is insulated, and a cold, wet, and ungenial climate supervenes. The forests decay more or less rapidly, while marshes and bogs extend their boundaries. Local glaciers exist in some of our mountain glens, and flooded rivers carry seaward the trunks and branches of many a fallen monarch of the forest. The sea at this time washes the 45–50 feet level, and along the shores live Neolithic fishermen who revel in a molluscan diet, and now and again succeed in capturing a whale.

Such, I believe, were the general conditions that obtained during the accumulation of the gravel and sand with drifted trees at Musselburgh. The peat and sand which overlie the tree-bearing beds belong to a much more recent time; but whether they are older or younger than the 25 feet beach there is no evidence to show. I need hardly add that the deposits of the 45–50 feet beach are of post-glacial age,—being younger than the estuarine-marine deposits of the 100 feet terrace,—which latter, as I have shown elsewhere, must be classed as of late glacial age.

4. On a Special Class of Partitions. By Professor Tait.

5. Observations on a Green Sun, and Associated Phenomena. By Professor C. Michie Smith.

6. Analysis of the Principles of Economics. Part V.—Psychological. By Mr P. Geddes.

7. On a Singular Electrical Result. By Mr Harry Rainy. Communicated by Professor Tait.

In order to observe the spectrum of coal gas at atmospheric pressure, I passed a stream of the gas through a tube open at both ends, and into the sides of which the platinum electrodes of an induction coil were inserted. I noticed that the spectrum gradually became narrower. On observing this, I stopped the current, and found that a filament of carbon had grown upwards from the lower electrode. On examining it carefully it appeared to have numerous short branches, all of which pointed in the direction of the electrode towards which the filament was growing. The time which it took to form between the electrodes was, I think, under two minutes.

PRIVATE BUSINESS.

A Ballot was then taken, and the following were elected British Honorary Fellows:—Professor E. Frankland, LL.D., F.R.S.; William Huggins, D.C.L., LL.D., F.R.S.; and Professor Burdon Sanderson, LL.D., F.R.S. The following were elected Ordinary Fellows:—David Alan Stevenson, Esq., B.Sc., C.E.; Sheriff Thoms; R. W. Mylne, Esq., C.E., F.R.S.; and William Evans, Esq., F.S.A.

Monday, 21st July 1884.

THE RIGHT HON. LORD MONCREIFF, President, in the Chair.

The President read to the Society a letter from M. Pasteur, Chairman of the Committee constituted for the purpose of erecting a Statue at Alais to the memory of Jean Baptiste Dumas. He intimated that the Fellows of the Society who wished to subscribe might send their subscriptions to the Librarian.

1. Observations on Coral Reefs and Calcareous Formations of some of the Islands in the Solomon Group. By H. B. Guppey, M.D., H.M.S. "Lark," with Notes by John Murray, Esq. Communicated by John Murray, Esq.

2. Further Note on the Compressibility of Water. By Professor Tait.

I had hoped to be able, during the winter, to extend my observations to temperatures near the freezing point, but the lowest temperature reached by the large compression apparatus was 6°·3 C.; while the highest is (at present) about 15° C. From so small a range nothing can be expected as to the temperature effect on the compressibility of water, further than an approximation to its values through that range.

The following table gives the mean values of the average compression per ton weight per square inch :—

Pressure in Tons.	1.	2.	2½.	3.	3½.	4
6°·3 C.	0·00704	692	684	672	...	...
7°·6	...	682	...	670	660	...
11°·3	684	670	...	654	...	...
13°·1	...	666	...	648	...	637
15°·2	673	654	...	633	...	...

These are all *fairly* represented by the expression

$$0{\cdot}00743 - 0{\cdot}000038\,t - 0{\cdot}00015\,p,$$

where t is the temperature centigrade, and p the pressure in tons weight per square inch. This, of course, cannot be the true formula, but it is sufficient for ordinary purposes within the limits of temperature and pressure above stated. It represents the value of

$$\frac{v_0 - v}{pv_0}.$$

With a new set of compression apparatus, very much larger and more sensitive than those employed in the above research, I have just obtained the following mean values for the single temperature 15°·5 C. :—

Pressure in Tons.	1.	1½.	2.	3.
Fresh water, . .	0·00678	663	657	638
Sea water, . .	0·00627	618	609	593

These are the values of $\frac{v_0 - v}{pv_0}$; and they give, for the true compressibility $\left(-\frac{1}{v}\frac{dv}{dp}\right)$ at any pressure, and temperature 15°·5 C., the formulæ,

Fresh water, . . $0·00698(1 - 0·05\, p)$
Sea water, . . . $0·00645(1 - 0·05\, p)$

The ratio is 0·925, *i.e.*, the compressibility of sea water at the above temperature is only 92·5 per cent. of that of fresh water.

[*Added* 28*th October* 1884.]

With the notation employed (*ante*, p. 229), $\left(\frac{de}{dp}\right) = 0·000038/152$ p being in atmospheres; while we have $e = (t - 4)/72{,}000$. Hence

$$\frac{\delta t}{72{,}000} + \frac{0·000038}{152}\delta p = 0\,.$$

Thus, for $\delta p = 152$ atmospheres, *i.e.*, 1 ton weight per square inch, we have

$$\delta t = -2°·74 \text{ C}.$$

This agrees, in a remarkable and altogether unexpected manner, with the result 2°·7 C. obtained by direct measurement (*ante*, p. 228).

3. Critical Note on the latest Theory in Vertebrate Morphology. By Mr J. T. Cunningham, B.A.

In the attempt to trace the vertebrate organisation by comparative anatomy and embryology back to a simpler state, the origin of the limbs has been made the subject of various hypotheses. Many years ago Gegenbaur brought forward a method of regarding the morphology of the limbs, by which each could be derived from a gill arch supporting a series of gill rays, from such a system as forms the skeleton of a gill in a typical Selachian of the present day. This comparison was instituted without any particular stress being laid on the relation of the ancestral vertebrate to invertebrate forms. He supposed that the central ray of the series in the branchia gradually grew more prominent, and as it increased in length the rays near it lost their attachment to the arch, and became articulated to the sides of the central ray: in this way he obtained an imaginary limb skeleton which he called the Archipterygium.

This theory is usually supported by reference to the structure of the limb skeleton of Ceratodus. The shoulder girdle of this animal is an arch of cartilage more or less ossified, with the upper end of which the free limb articulates. This limb is composed of an axial rod of cartilage broken up into a series of short segments, and on each side of this cartilaginous axis a series of cartilaginous rays is situated: each ray articulating with one of the segments of the axial rod.

In another Dipnoan, Protopterus, there is a still more striking indication of the relation between limb and branchia. In this animal the shoulder girdle, as Wiedersheim pointed out, has a deeper position than it has in other fishes, a position in relation to the surface of the body similar to that of the branchial skeleton. In the second place, the shoulder girdle of this animal bears throughout life functionally active external gills; and thirdly, not only the shoulder muscles, but the whole limb as well, are innervated in great part by branches of the vagus nerve.

On this hypothesis of the morphology of the limbs, the original position of the limb would have been such, that the plane in which it was expanded was vertical to the longitudinal axis of the body, as it is in Teleosteans and Ganoids. But in Selachians, although in adult life the plane of the limb in most cases approaches this

position, in the embryo the limb grows out in a plane parallel to the axis of the body; and as there is every indication that to the Selachians we must usually look for the most primitive condition of vertebrate organs, this is a strong argument against Gegenbaur's hypothesis. Based on a study of the development of the limbs in Selachians, is the view of the morphology of the limbs advocated by Thacker, Mivart, and Balfour, and especially supported by the researches of the latter. According to this view, which like the branchial hypothesis of Gegenbaur, makes no attempt to bring the supposed original condition into relation with the organisation of any invertebrate form, the two pairs of limbs in fishes are the specially modified remnants of a longitudinal fold, which originally ran along each side of the body, and was similar in structure to the median folds from which the unpaired fins are derived. The embryological facts which support this view are briefly thus. In Selachians the first rudiments of the paired fins appear as slight longitudinal ridge-like thickenings of the epiblast similar to the rudiments of the unpaired fins. There are two such ridges on each side—one anterior behind the last branchial arch, one posterior on the level of the cloaca. In most Elasmobranch embryos, especially in Torpedo, they are connected by a line of columnar epiblast cells, which very soon disappears. The presence of this connecting ridge is suggestive of the original continuity of the two fins, on each side. As the fin grows out mesoblast extends into it, and in the mesoblast appears embryonic cartilage, which breaks up into a longitudinal series of rays, and these are continuous at their base with a longitudinal bar termed by Balfour the basipterygium. From the anterior end of this longitudinal cartilage there pass off an upward and a downward process, which form the rudiment of the limb girdle. The longitudinal bar may be due to secondary development, the series of cartilaginous rays being the primitive part of the fin which is thus reduced to the same structure as an unpaired fin. The pelvic fin in a Selachian never departs much from the primitive arrangement, the only alteration being that the basipterygium segments between the anterior and succeeding ray, and the posterior end of it segments off as the terminal ray. In the pectoral fin the changes are more extensive: the basipterygium is rotated outwards from the body until it forms the posterior border of the limb, and constitutes

that part of the adult fin called metapterygium by Gegenbaur, and then becomes segmented off from the pectoral girdle articulating with its hinder edge. The propterygium and mesopterygium are merely the anterior part of the original basipterygium which divides into two pieces, articulating directly with the pectoral girdle. Thus the metapterygium is the homologue of the basal cartilage of the pelvic fin. It is obvious that the facts of the development discovered by Balfour are absolutely incompatible with Gegenbaur's view of the origin of the limb from a branchial arch and its rays. According to Gegenbaur's view, the limb of Ceratodus is the most primitive form, and the metapterygium in the Elasmobranch corresponds to the central axis in Ceratodus, the posterior rays having disappeared. The development of the fins in the dog fish shows that the metapterygium is the basal part of the fin grown outwards, and could never have borne posterior rays.

In the earliest sketch of the genealogy of vertebrates put forward by Dr Dohrn in 1875,* he also maintained that the vertebrate paired limbs originated from gills, not gills constructed on the plan of those of a fish of the present day, but branched tree-like gills resembling those of living annelids, such, for example, as those of *Arenicola piscatorum.* He supposed that special muscles first became separated from the dermo-muscular tube, in order to move the gills for the sake of more efficient respiration; that then the gills began to be used as locomotive organs; and finally, when respiration was confined to the anterior gill slits, two pair of these gills were preserved, and completely changed into locomotive organs on account of the suitability of their position for keeping the equilibrium of the cylindrical body in the water. The assumption in this view, that a limb was originally a process of a single somite of the body, could not well be maintained in face of the facts of the structure and development of the fins of fishes. In Elasmobranchs it is obvious that a lateral fin belongs to several somites of the body, not to a single one. Balfour found that the muscles of a limb in an embryo Elasmobranch were derived from buds of several muscle plates, that is from several somites. In a recent paper † on the orgin of the paired and unpaired

* *Ursprung der Wirbelthiere,* Leipzig, 1875.

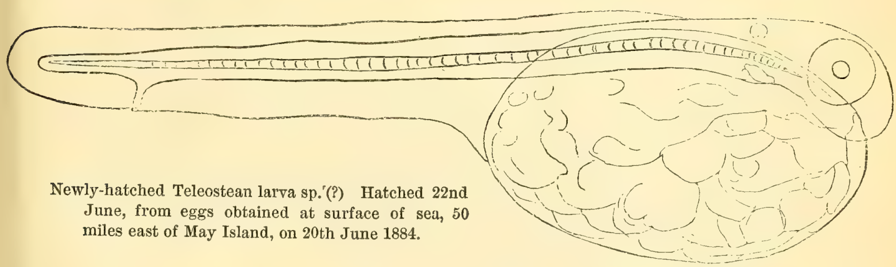
† "Studien zur Urgeschichte des Wirbelthierkörpers VI." *Mittheil. aus der Zoologischen Station zu Neapel,* Band V. Heft 1.

fins of Selachians, Dr Dohrn abandons his former view, and gives a detailed account of the origin of the musculature of both median and paired fins. He confirms Balfour's statement of the origin of the musculature of the paired fins from buds of the muscle plates, and extends the same to the unpaired fins. He also shows that muscular buds, similar to those which form the muscles of the pectoral fin and pelvic fin, are given off in those myotomes which belong to the part of the trunk between these, but afterwards atrophy. This fact confirms Balfour's view, that the pectoral and pelvic fins were originally continuous. He then shows that muscle buds similar to those which form the muscles of the pelvic fins are given off behind the anus, forming a continuous series with those belonging to the pelvic fin; and that from these the muscles of the anal fin are derived. From this, he argues that the anal fin has been formed phylogenetically from the ventral coalescence of two lateral folds continuous with those whose remnants form the pectoral and pelvic fins. The reason why coalescence has taken place posteriorly, and not in the region anterior to the anus, is that the gut has disappeared from the posterior end of the body, and not from the anterior pre-anal part. The gut is shown by the existence of the embryonic post-anal gut to have originally extended to the posterior extremity of the body where the original anus was, while after the formation of the present anus, a secondary structure, the posterior part of the gut disappeared, and then by the reduction in size of the ventral part of the tail, the two lateral folds were brought together and formed the median ventral fin. He further shows that the musculature of the dorsal median fin arises from muscle buds given off on each side from the dorsal ends of the myotomes, and concludes from this, since similar ventral buds form two lateral fins, that the dorsal fin was also orignally derived from the coalescence of two lateral fins. The effective cause for the coalescence here was, in his opinion, the folding over of the original flat plate of the central nervous system to form a canal. Going one step further back, he supposes each of these four lateral folds, composed as they are, of buds from successive segments, to have been originally a series of separate processes; and then he points out that we have an animal similar to an annelid, each segment bearing a pair of notopodia, and a pair of ventral neuropodia.

To trace the supposed transformation in the reverse order, it is thus. The original annelid-like ancestor first of all changed its position in locomotion, so that its nervous system became dorsal instead of ventral. Then, by the folding over of its median nervous plate to form a tube, the two series of neuropodia were brought together, coalesced, and formed the dorsal fin of the fish.

The animal having obtained a new anus some distance from the end of the body, the posterior part of the intestine disappeared, being no longer funtional; and by the consequent reduction of this part of the body, the posterior part of the two series of notopodia coalesced in the median line and formed the anal fin. Anteriorly the successive notopodia united in two separate regions to form the pectoral and pelvic fins, and in the intermediate region disappeared.

In the course of my observations on the development of floating Teleostean ova, carried on in the month of June last, I was im-



Newly-hatched Teleostean larva sp.'(?) Hatched 22nd June, from eggs obtained at surface of sea, 50 miles east of May Island, on 20th June 1884.

pressed with the incompatability of Dohrn's ingenious theory, with the existence of a pre-anal ventral median fin in the larvæ of one species. The larvæ in question were hatched in the Scottish Marine Station at Granton, from transparent floating eggs obtained by means of a fine tow-net in considerable numbers, about 50 miles east of the Isle of May. I do not know at present to what fish the ova belong, but as the ova and embryos are well characterised, they may be identified at some future time with eggs taken from some ripe adult fish. The yolk in both the developing ovum and the hatched larva is extremely pellucid, and divided into separate portions with polygonal outlines: there are no oil-globules in the yolk, the notochord is composed of a single column of vacuolated cells in the formed embryo, and in the larva the anus is situated at some distance from the yolk-sac and close to the posterior extremity of

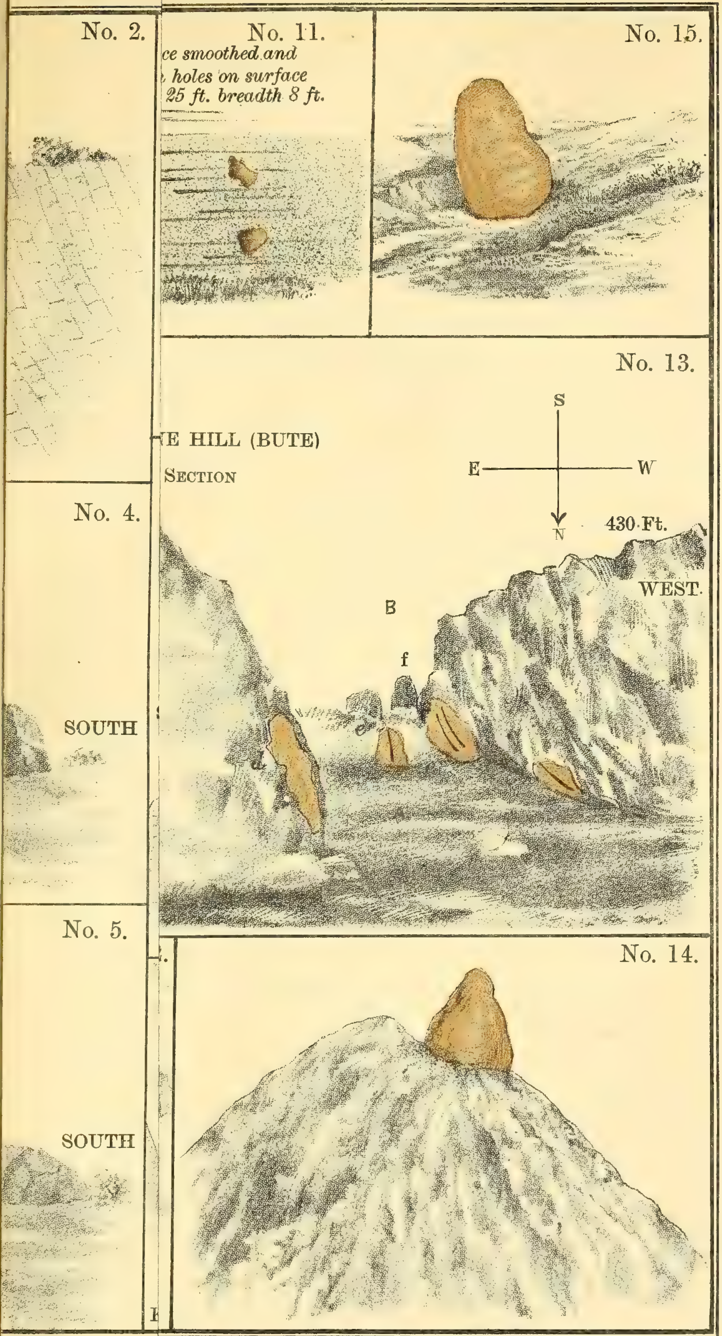
the body. The newly-hatched larva is 3 mm. in length. A larva with these characteristics is described by Von Hensen in the fourth Report of the *Commission zur Untersuchung der Deutschen Meere in Kiel,* part ii.; the species is there also left undetermined. The relation of the ventral median fin to the anus is not discussed by Von Hensen. This relation is as follows, and is shown in the woodcut. The median fin extends continuously along the median dorsal line round the end of the tail to the anus, and passes continuously from thence to the yolk-sac, having about the same breadth throughout. There is no break in the fin at the anus, as the latter opens on the edge of the fin, the terminal portion of the intestine projecting downwards from the trunk.

There is at least one other Teleostean larva in which the primordial median fin has exactly the same relations to the anus and yolk-sac as in the larva just described. This second case is that of the herring. The existence of a pre-anal portion of the median ventral fin in the herring larva was pointed out by Dr C. Kupffer* in 1878, but he includes it in his general description, laying no particular stress on it.† Balfour, in his *Comp. Embryology,* although he refers to Kupffer's work, has overlooked this fact in the structure of the herring larva, making the general statement that in the young Teleostean the ventral fold of the median fin ends anteriorily at the anus.

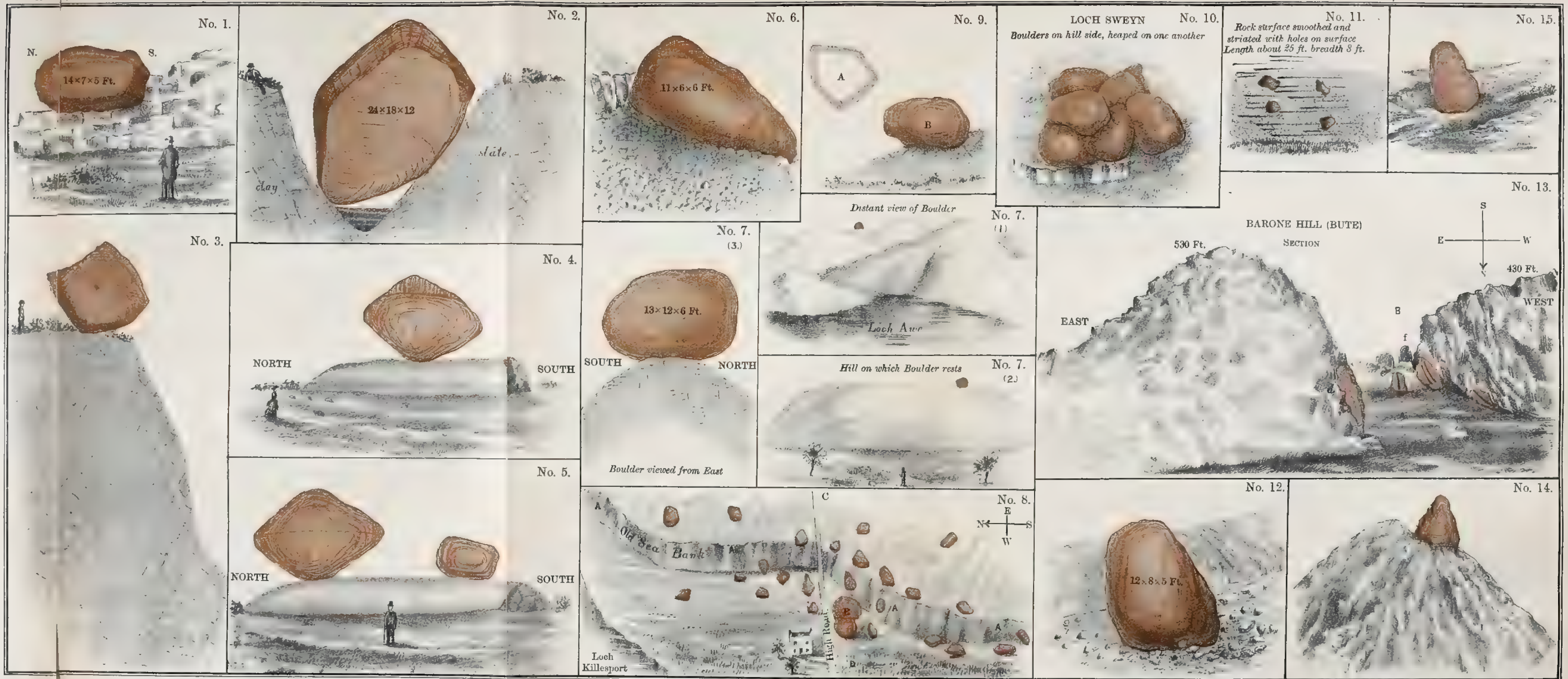
It is uncertain whether there are other Teleostean larvæ in which the same state of matters obtains, and I do not know at present what relation the development of the pelvic fins bears to the ventral median fold in the two cases mentioned. On the two occasions, when I had the undetermined larvæ above described in the laboratory, I was unable to keep any alive for more than six days after hatching. At the end of that time the pre-anal ventral fin was still unchanged, and no trace of pelvic fins could be seen,

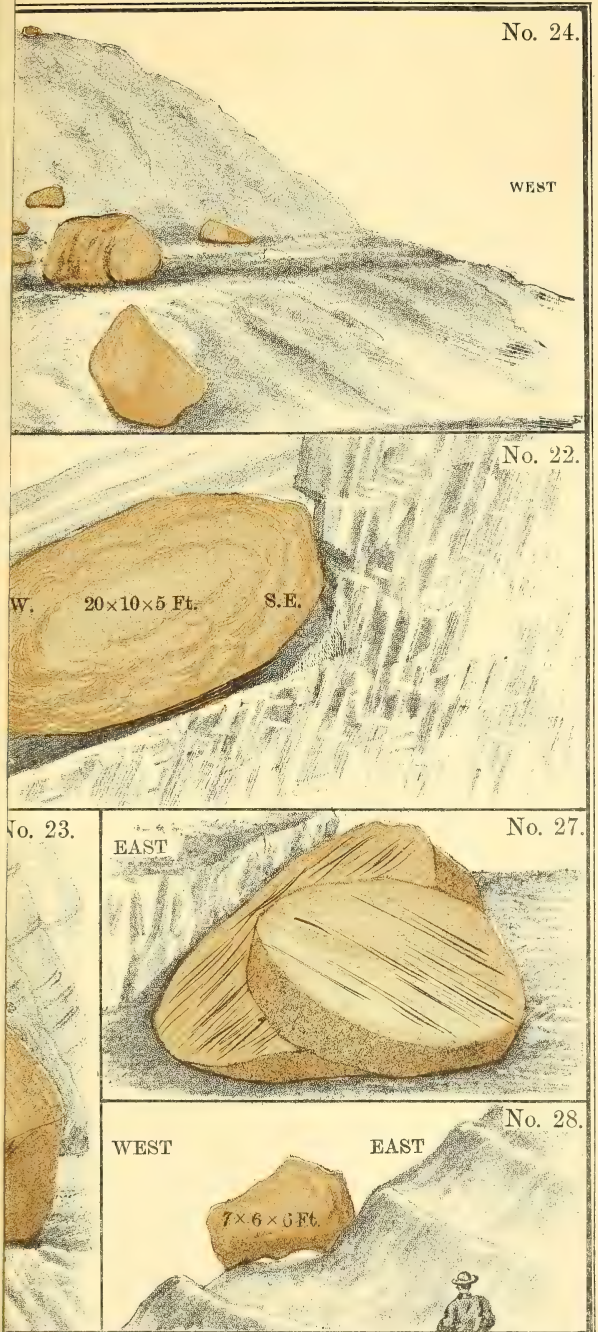
* *Laichen u. Entwicklung des Ostsee Herings,* Berlin, 1878.

† Having carefully studied the development of the herring in the month of August, I can fully confirm Kupffer's description of the newly-hatched larva. The proportion of the length of the body through which the pre-anal ventral fin extends is considerable, the whole length of the larva being 5·2 mm., while the length of the pre-anal fin is 2·5 mm. The larva of the herring is closely similar to the first larva described above; it is quite transparent; the yolk consists of separate spherules, and the notochord has but one column of cells. (*Note added Sept.* 19, 1884.)



W. & A. K. Johnston, Edinburgh & London.


No. 1.
N.
S.
14×7×5 Ft.
No. 2.
24×18×12
slate
clay
No. 6.
11×6×6 Ft.
No. 9.
A
B
LOCH SWEYN
No. 10.
Boulders on hill side, heaped on one another
No. 11.
Rock surface smoothed and striated with holes on surface Length about 25 ft. breadth 8 ft.
No. 15.
No. 3.
No. 4.
NORTH
SOUTH
No. 7. (3.)
13×12×6 Ft.
SOUTH
NORTH
Boulder viewed from East
Distant view of Boulder
No. 7. (1)
Loch Awe
Hill on which Boulder rests
No. 7. (2)
No. 13.
BARONE HILL (BUTE)
SECTION
530 Ft.
430 Ft.
S
E
W
EAST
WEST
B
f
d
No. 5.
NORTH
SOUTH
No. 8.
N
E
S
W
A
C
Old Sea Bank
High Road
B
Loch Killesport
No. 12.
12×8×5 Ft.
No. 14.



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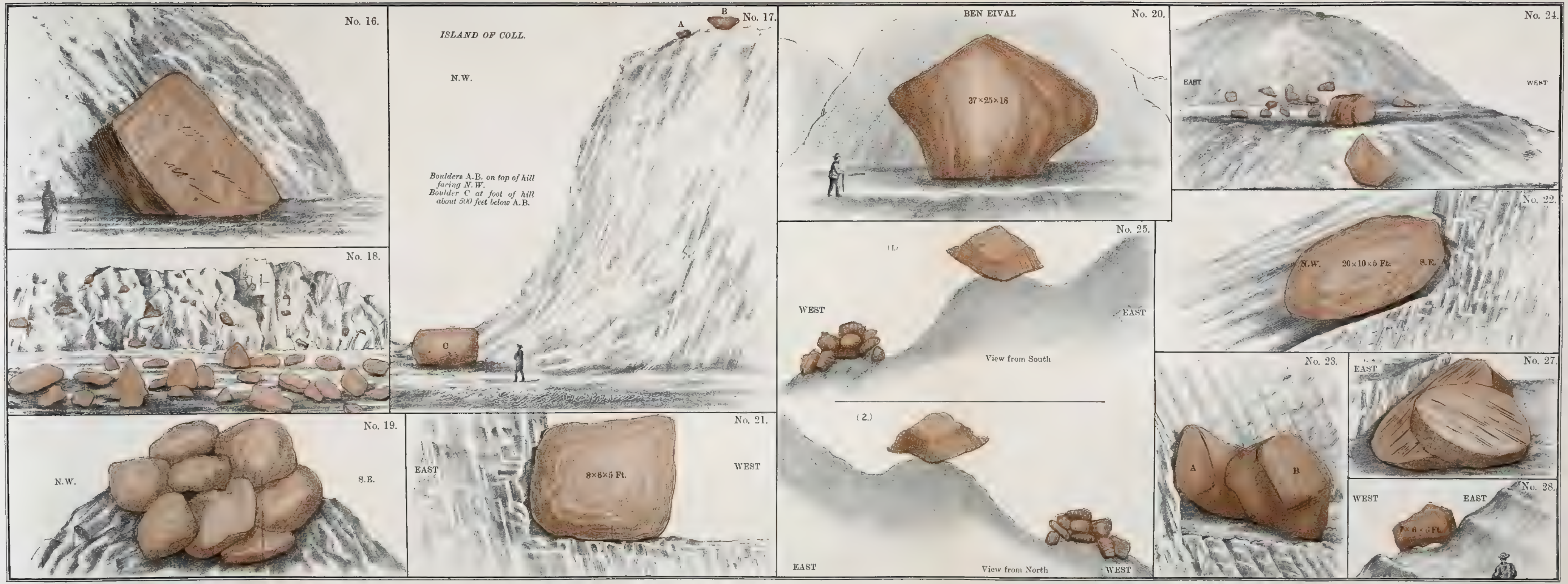
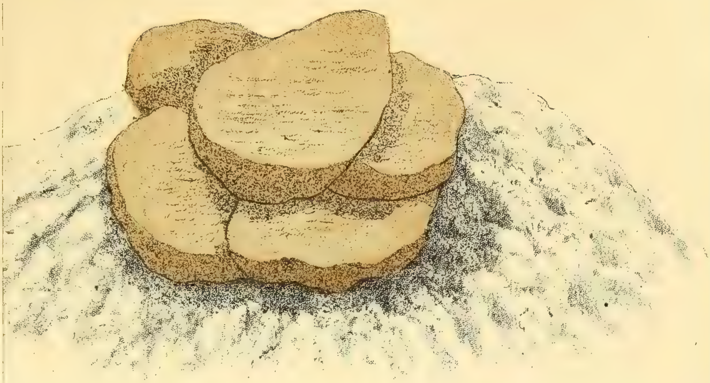

No. 16.
No. 17.
ISLAND OF COLL.
N.W.
A
B
Boulders A.B. on top of hill facing N.W.
Boulder C at foot of hill about 500 feet below A.B.
C
No. 18.
No. 19.
N.W.
S.E.
No. 21.
EAST
WEST
8×6×5 Ft.
BEN EIVAL
No. 20.
37×25×18
No. 25.
WEST
EAST
View from South
(2.)
EAST
View from North
WEST
No. 24.
EAST
WEST
No. 22.
N.W.
20×10×5 Ft.
S.E.
No. 23.
A
B
No. 27.
EAST
No. 28.
WEST
EAST

No. 43.



No. 44.

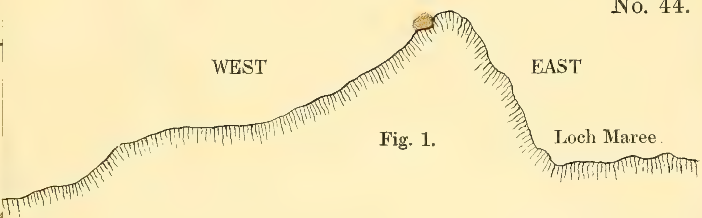


Fig. 1.

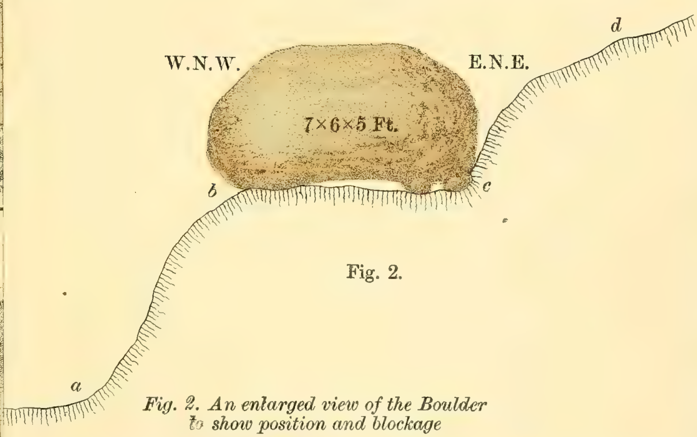


Fig. 2.

Fig. 2. An enlarged view of the Boulder to show position and blockage

c d is a section of the part of the hill on which the boulder rests; *a b* is a cliff about 30 feet, nearly vertical; *b c* is a shelf on which the boulder rests; *c d* is a steep ledge of rock against which the boulder abuts at its east end. It there rests partly on rock, partly on small boulders.

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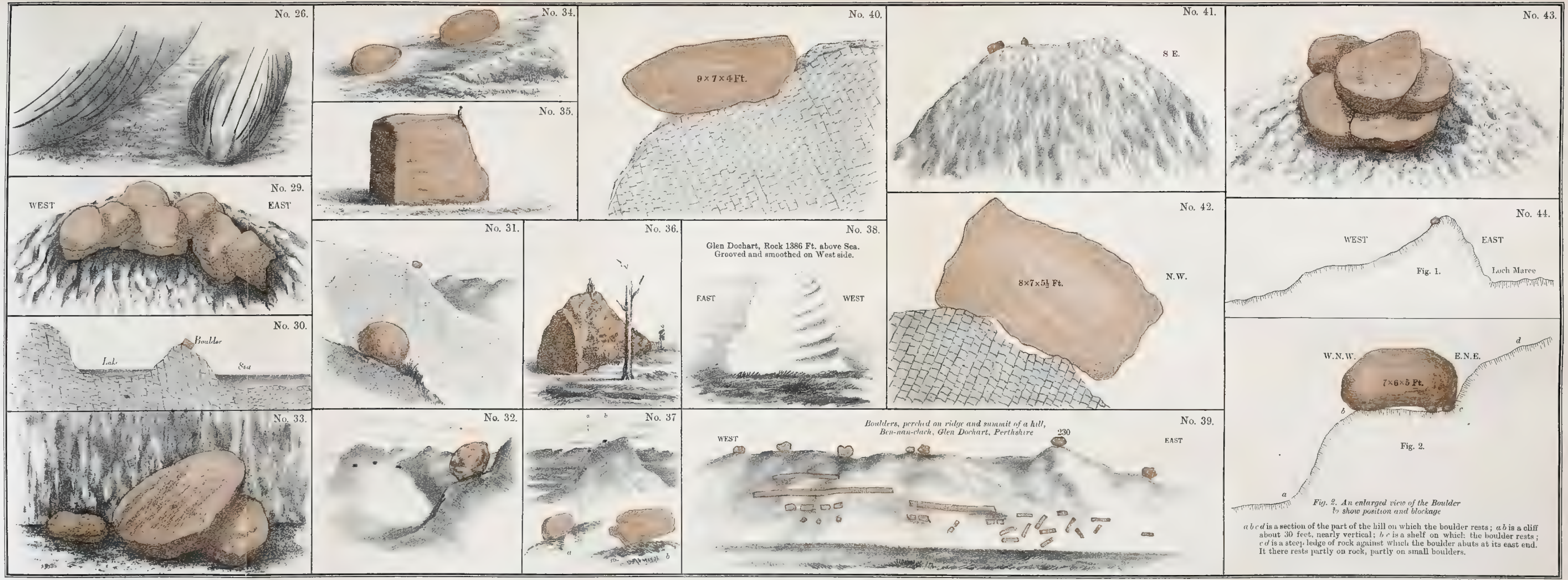


Fig. 2. An enlarged view of the Boulder to show position and blockage

abcd is a section of the part of the hill on which the boulder rests; *ab* is a cliff about 30 feet, nearly vertical; *bc* is a shelf on which the boulder rests; *cd* is a steep ledge of rock against which the boulder abuts at its east end. It there rests partly on rock, partly on small boulders.

W & A K Johnston Edinburgh & London

although the pectoral fins were present as horizontal folds with a semicircular outer border.

It is obvious that unless the pre-anal ventral fin in the cases mentioned can be explained as a secondary arrangement of certain Teleosteans (a supposition which is not rendered more probable by the fact that the herring is a physostomous form with pelvic fins in their original position), its presence forms an obstacle to the universal application of Dohrn's theory; and a re-examination of this most interesting subject is necessary in view of the facts I have pointed out. From Dohrn's point of view the coexistence of functional intestine and median ventral fin in the same part of the body is impossible.

4. Tenth and Final Report of the Boulder Committee; with Appendix, containing an Abstract of the information in the Nine Annual Reports of the Committee; and a Summary of the principal points apparently established by the information so received. (Plates VIII. to X.)

The Committee are of opinion that it is now time to submit a final Report to the Council. Nine Annual Reports have already been presented, extending altogether to about 400 pages, as printed in the *Proceedings* of the Society. The appointment of the Committee took place in April 1871, and the first Report was presented in April 1872, by which time a considerable number of answers were received to circulars sent by the Committee, first to the parochial clergy, and next to the parochial schoolmasters, asking for information.

The Committee do not expect that, by continuing inquiries on the lines available to them, much additional information of importance would be obtained. At all events, it is now desirable to arrange the information which has been obtained, in such a way as to make it more readily accessible—as, for example, to show, in what districts the most interesting Boulders are situated, and also to indicate the conclusions which the positions of the Boulders, or any markings on them, suggest.

Before, however, explaining the means which the Committee have agreed to adopt for classifying the information obtained, the Committee think it right to record, in a few sentences, the circumstances which led to the appointment of the Committee.

The subject of the transportation across the country of masses of rock by some natural agency, has from a very early period been discussed in the Royal Society of Edinburgh. In the year 1812, Sir James Hall, the Society's President, was the first to break ground, by reading a valuable Memoir, afterwards published in the Society's *Transactions.* The subject was from time to time again brought before the Society by different Fellows,—whose names merely may be mentioned,—viz., Principal James Forbes, Professor Fleming, Professor Nicol, Mr James Smith of Jordanhill, Mr Charles Maclaren, Mr Robert Chambers, Rev. Thomas Brown, and Mr Milne Home. The facts brought forward in this way, of course, were only such as happened to have been noticed in particular districts by individual observers. But as it was known that the distribution of Boulders was universal over Scotland, not only on the Mainland, but on the Islands of the Hebrides, Orkneys, and Shetland, it was felt, in order to pave the way for a complete discussion, that inquiries of a more comprehensive character were desirable.

In the year 1870, Mr Milne Home received a communication from Professor Favre of Geneva, stating that an inquiry of this character had, with the co-operation of the Swiss Geological Society, been commenced in Switzerland; that the Geological Society of France had resolved to follow the example; and he expressed a hope that Mr Milne Home, who he heard had taken some interest in the Boulder question, would endeavour to institute a similar inquiry for Scotland.

Mr Milne Home submitted this correspondence to the late Sir Robert Christison, and he having expressed approval of Professor Favre's suggestions, Mr Milne Home read a paper in the Society, embracing his correspondence with the Swiss Professor, and suggesting the appointment of a Committee, with power to make the requisite inquiries. Such a committee was shortly thereafter (April 1871), on the motion of Sir Robert Christison, appointed by the Society's Council.

Altogether about 1500 circulars were issued by the Committee; answers to a considerable number of which were, in the course of the

following year, received. About one half of these answers supplied information, which gave materials for the two first Reports. Most of these answers were useful also, by indicating the localities of remarkable Boulders, and thus enabling members of the Committee to visit them.

In recording the information from time to time obtained, the Committee could do no more in preparing the Annual Reports than mention the particular county where the Boulder was reported to be situated. The consequence is, if any one wishes to discover what or where are the Boulders, described as occurring in any particular county, he must hunt through the whole nine Annual Reports to obtain this knowledge.

In order to remove this inconvenience, the Committee have framed a compendium or abstract of the whole information in these Reports, so as to represent for each county, in alphabetical order, what is said in them regarding Boulders. This abstract will be found in Appendix I.

In addition to a geographical arrangement of the information contained in the Annual Reports, it occurred to some members of the Committee, that it would be useful to have a Summary of the most material facts found in the Reports, and of the inferences which these facts suggest, in so far as they seem to throw light on the question, by what agency Boulders could have been transported. Such a Summary has been undertaken by the Convener, and it forms Appendix No. II. This Summary consists almost entirely of the facts set forth in the Annual Reports and in Appendix I.; but the inferences from these facts involve opinions in which all persons may not agree. Therefore the Committee do not commit themselves either to the adoption or to the rejection of these opinions, though they quite allow that they are valuable as indicating points worthy of consideration.

The Committee, whilst aware that their business was to investigate the subject of Scotch Boulders, have not deemed it any departure from the objects of their appointment to advert to well authenticated cases of Boulders situated in English counties, which have been on good grounds traced to parent rocks in the south of Scotland (*Abstract*, pp. 796, 797, 838, and 852).

The bearing of this discovery on the direction of Boulder

transport, both in England and in Scotland, is very obvious, and will no doubt be noticed in the forthcoming General and Final Report of the British Association Boulder Committee.

It may here be right to remark, that the appointment of the English Boulder Committee, which took place at the Meeting of the British Association at Edinburgh in August 1871, was at the instance of Professor Archibald Geikie, who, in advocating the appointment, remarked on the importance of extending to England and Ireland the inquiry, which had already commenced in Scotland.

The Convener learns from the Rev. Mr Crosskey, Chairman of the English Boulder Committee, that his Committee intend soon to frame an Abstract of their nine Annual Reports.

These Final Reports, embracing the most interesting discoveries on this subject in England and Scotland respectively, may, it is hoped, throw new light on a subject of much geological interest.

DAVID MILNE HOME, *Convener.*

EDINBURGH, 24*th June* 1884.

APPENDIX I.

Abstract of Information in the Nine Annual Reports of the Committee.

Aberdeenshire.

Aberdeen, Town of.—In excavating for foundation of house in Union Street, a boulder of syenitic granite, with hornblende crystals, found 6 × 5 × 4 feet, weighing about 2½ tons. The under surface of boulder covered with ruts, all parallel with longer axis, some o them 3 feet long. Longer axis pointed E. and W. No rock like that of boulder nearer than Belhelvie, 10 miles to north, or Huntly, 40 miles to N.W., or Ballater, about 40 miles W.S.W. Dr Cruickshank having, in July 1870, got notice of the boulder, made it known to late Professor Nicol, who caused it to be split, and the striated part set up in court of Marischall College (*First Report*, p. 21, and letter to Convener from Dr Cruickshank).

A syenite boulder 5 × 3 × 1½ feet, with striæ parallel to longer axis, built into a wall in *King Street Road.*

In Aberdeen newspaper of November 1881, account given of granite boulder, weighing about 8 tons, at the east end of *Urquhart Road*, found in excavating a bed of sand.

Mounds and ridges of shingle and gravel, all water rolled, abound north of Aberdeen, near shore. Large boulders of trap, granite, and gneiss rest on top and surfaces of these ridges.

Foveran.—In a field on Drums Farm, a huge granite boulder, called "*The Grey Stone*," measuring 54 feet in circumference, with a height of 7 feet above ground. Another block, also apparently a transported mass, measures 78 feet in circumference, and projects 6 feet out of ground. A little to the north of Drums, on one of these gravel ridges, lies a boulder, 8 × 5 feet. A layer of red clay about 9 inches thick, overlies the gravel. Boulder rests on gravel, but *clay over the gravel encircles its base* (*Seventh Report*, p. 39).

Ballater.—Morven Hill, 2963 feet above sea, is situated a few miles north of Ballater. It stands many miles apart from any hill

of like elevation. Boulders of granite, quartzose gneiss, and laminated quartz lie on western brow of mountain and up to summit. No granite rocks occur *in situ* in Morven. Rocks there consist of greenish hornblende and white felspar (*Seventh Report*, p. 40).

Belhelvie.—Sienitic boulder about 8 feet in diameter, called "*Kepple Stone*," near public school. Rocks *in situ*, near boulder, are *granite* (*First Report*, p. 21).

Bourtie.—Several greenstone boulders (supposed to be Druidical) —called "*Altar Stone*," weighing 18 tons; "*Bell Stane*," weighing about 20 tons; "*Wallace's Putting Stone*," 24 feet in girth; and other two, called "*Piper's Stone*" and "*Maiden Stone*."

Boddam.—Near the Bullers of Buchan stands the *Hare* or *Cleft Stone*, a granite boulder 9 × 8 feet, which marks boundary between parishes of Cruden and Peterhead.

Another granite boulder, in a ravine, 14 × 8 × 5 feet; another 18 × 12 × 5½ feet; another 13 × 9 × 5 feet. Along the south side of Peterhead Bay, and as far as Buchan Ness, the shore strewed with blocks of granite, gneiss, trap, and sandstone; many of them composed of rocks not found nearer than 20 or 30 miles (*First Report*, p. 23, and *Second Report*, p. 20).

In Boddam Dean, a granite boulder called "*The Hanging Stone*," 37 feet in girth and 27 feet over it. Half a mile east, another of 20 tons. Huge granite boulder, called the "*Grey Stone of Ardendraught*," was broken up in the year 1779 to build walls of a new parish church. It was the stone on which "*All Hallow fires*" used to be lighted (*First Report*, p. 2).

Braemar.—There is a hill close to village named "*Cairn-a-Drochet*," reaching an elevation of 2700 feet. Near the top of the hill, viz., about 70 yards to the north, lies a block of coarse granite 12 feet long, with many other boulders of the same kind. The rocks of the upper part of the hill consist not of granite, but of quartzose gneiss. Opinion expressed by Mr Jamieson of Ellon, that the large block, and many of the others near it, came from mountains to the north, the granite of which is identical with that of the boulders. In letter to Convener, Mr Jamieson mentions that, near shooting lodge on this hill, there is a cluster of four or five immense granite boulders touching one another (*First Report*, p. 22, and *Seventh Report*, p. 41).

Ben Uarn More forms the culminating peak of the great ridge

that divides the shires of Aberdeen and Perth, reaching to a height of 3587 feet. Mr Jamieson found blocks of a peculiar porphyry on the northern slope of the hill, near the top; but no such rock exists there *in situ*. The rock of the hill is quartz (*Ibid.*).

Chapel Garioch.—Boulder $19 \times 15\frac{1}{2} \times 11\frac{1}{2}$ feet, weighing about 250 tons. Longer axis E. and W. The boulder differs in composition from rocks adjoining. It rests on *drift*. Legend, that thrown by Devil, from Bennachie Hill, which is situated to N.W. (*First Report*, p. 22).

Culsalmond.—Boulder of blue gneiss, $6\frac{1}{2}$ feet high $\times$ $5\frac{1}{2}$ feet in girth, known to archæologists as the "*Newton Stone*,"* having on it Ogham and other very antique inscriptions (*First Report*, p. 24).

Kemnay.—Seven large boulders of gneiss, whilst rocks adjoining are granite. The largest weighs about 380 tons. Most of them lie on hill-sides facing W. and N.W. The gneiss hills of Bennachie and Cairnwilliam from which these boulders are supposed to have come, are situated towards W.N.W. and N.W., distant 6 or 8 miles. The valley of Don is between these hills and the boulders.

On Quarry Hill, situated not far from these boulders to north, rock striations show movement from west (*First Report*, p. 24, and *Second Report*, p. 148).

To the S.E. of the above boulders, another bluish-grey granite boulder called "*Soutar's Stone*," weighing about 270 tons. Height above sea about 500 feet. Lies in muddy sediment, on a hill-side facing N.W. A hill, running N. and S. for 500 yards, lies to N.W., about a quarter of a mile distant, and with ridge about 100 feet above boulder. If boulder came from N.W., it must have been carried across top of this hill (which is very improbable), or else have come round one end, and have been carried by an eddy into its present position (*Second Report*, p. 148).

Striations on rocks here show movement from W.

New Deer.—Many boulders from 1 cwt. to several tons in weight lie in a sort of line for more than a mile south from farm of Green of Savoch, as far as to the hill of Coldwells and Toddlehills in

* For speculations regarding the inscriptions, see *Trans. Soc. of Scottish Antiquaries*, for years 1862 and 1882. Mentioned in last paper, that another gneiss boulder of much same size stands near, with figure of a serpent on it, barred with the Z-shaped sceptre symbol.

Added that Culsalmond parish abounds with relics of paganism.

Ellon parish. In this parish formerly, a rocking stone called "*The Muckle Stane of Auchmaliddie.*" A (so called) Druidical block formerly on Culsh Hill (Pratt's Account of Buchan, 1858). On Whitestone, Ellon, and Dudwich Hills, *chalk flints* found abundantly (*First Report*, p. 25).

Towie.—Block of unhewn granite, reaching a height of 7 feet above the ground, on north side of river Don, near bridge. Supposed to be Druidical (*First Report*, p. 25).

Cruden.—Granite boulder measuring 37 feet in girth and 27 feet over it, supposed to be Druidical. Another weighs 20 tons. Another huge granite boulder, on which said, that "*All Hallow Fires*" used to be lighted (*First Report*, p. 22).

Ellon.—Several boulders, one $22 \times 9\frac{1}{2} \times 8\frac{1}{2}$ feet, and another still larger, which have come from W. or W.N.W. (*First Report*, p. 24).

Glass.—Several large boulders differing from adjoining rocks, more than 1000 feet above sea.

1. Notes by Mr T. F. Jamieson, Ellon (from *Quarterly Journal of London Geological Society*, 7th Feb. 1866) :—

(1) On coast, south of Fraserburgh, there are several localities where the rocks are smoothed and striated in such a way as to show a movement over them from 40° N. to 60° W.

(2) In the neighbourhood of Peterhead (at Invernettie Brick-work), many boulders of red and grey sandstone, and also of a tough greenish coloured stone, all which resemble rocks that occur in Caithness, but not in the adjoining parts of Aberdeenshire (*First Report*, p. 29).

(3) At *King-Edward*, "there are deep masses of unstratified pebbly mud of a dark grey colour, very hard and firm, containing stones (some of which are ice-worn and striated), and fragments of shells, which are likewise occasionally *scratched.* It is like the Caithness drift in every respect."—"Besides this coarse stony mud, there are some beds of fine stratified sand, which often contain remains of shells in considerable abundance, most of them broken, but many of them entire."—"There is another bed of fine dark grey silt, free from stones, containing arctic shells entire, and apparently *in situ*, with the epidermis on." The *Tellina calcaria* occurs here of large size, with both valves connected by the ligament and shut.

Argyleshire.

Kintyre.—(1) At Southend, and also along east coast, south of Campbelton, the Convener saw and examined a number of boulders of a whitish-grey colour, which the schoolmaster considered to be granites, adding, that he knew of no *rocks* of that nature in Kintyre.

The Convener found pebbles of same rock in gravel pits at Campbelton, and was there informed that *rock* of same nature occurs to the north of Campbelton. Professor Nicol of Aberdeen, when he visited Kintyre, saw these boulders, and thought they had been transported from Arran, where there is rock of the same kind; in which case, they must have travelled 25 miles across the deep hollow of Kilbrennan Sound in a direction from N.E. (*Quarterly Journal of London Geological Society*, vol. viii. p. 422).

About a mile to east of Campbelton, smoothed rocks occur, dipping or sloping N.N.W.—as if smoothing agent had come from that quarter (*Sixth Report*, p. 5).

(2) Near *Kilhenzie*, a few miles west of Campbelton, a hill reaching to a height of from 500 to 600 feet, is covered with drift, and (on its western slopes) with gneiss and mica slate boulders, several weighing above 150 tons.

Old Red Sandstone rock on west coast, covered with drift; and on the drift, boulders of granite and gneiss. Diagram given in *Sixth Report*, representing these on a bank sloping down N.N.W. towards sea, at angle of 25°.

A boulder of gneiss found lying on mica schist strata, blocked at south end; its longer axis lying N. by E. and S. by W. Boulder said to have come from north (*Lithograph* No. 1, Plate VIII.).

In a fissure of the mica slate strata on the sea-shore of west coast near Tangy Burn (the fissure running N.W. and S.E.), a boulder of hard gneiss, weighing about 15 tons, has fallen into the fissure. It presses on S.W. wall of fissure, showing that the boulder had probably come from some N. or N.E. point. Fissure about 6 feet wide.

A chip of one of the granite boulders found on west coast, having been submitted to Professor Heddle, he said that it was a peculiar variety, well known in the Mourne Mountains in the N.E. of Ireland, on account of there being frequently in it crystals of topaz. In the chip from Kintyre, sent to him by Convener, the Professor found two topaz crystals.

Loch Long.—On ridge (about 350 feet above sea), between this Loch and Gareloch, there are several boulders of mica slate. Largest 11 × 6 × 6 feet. The rocks *in situ* are clay slate. Longer axis in most is N. by E., parallel with Loch Long valley. Two of boulders blocked at south ends.

In the Gareloch, on east beach, a little below Shandon, a gneiss boulder 18 × 15 × 12 feet (240 tons), with sharp end pointing N.W. At that end, surface is smooth—at south end, surface is rough.

In *Third Boulder Report* (p. 5), reference made to an account of the grey granite boulders seen by the late Charles Maclaren, amounting in number to several hundreds, one weighing 30 tons. Mr Maclaren inferred that these had all come from N.N.W. The opinion of Dr Robert Chambers and Sir Roderick I. Murchison also referred to.

On east side of the loch, opposite to Ardentinny, gneiss boulder called "*Jenny Meullens*," weighing about 380 tons, lying jammed in a gorge formed by rocky banks of a rivulet (*Lithograph* No. 2, Plate VIII.). Seemed from position to have come from north (*Third Boulder Report*, p. 1).

Another gneiss boulder 12 × 8 × 8 feet, with longer axis N.W. by N. Striæ on rocks adjoining run N. 2° or 3° W. The smoothed surfaces of rocks dip towards north.

On *Loch Goil*, above Carrick Castle, gneiss boulder called "*Clach Udalain*" (*i.e.*, "*Stone unstable*"), at height of 1526 feet above sea, lying on clay slate (about 300 tons) (*Lithograph* No. 3, Plate VIII.) (*Third Report*, p. 2).

Loch Goil and Loch Long, junction of.—"*Giant Putting Stone*," resting on smoothed rock 450 feet above sea. Rocks smoothed only on north aspects (*Lithograph* No. 4, Plate VIII.).

Knap Farm.—Several boulders lying on similarly smoothed rocks (*Lithograph* No. 5, Plate VIII.).

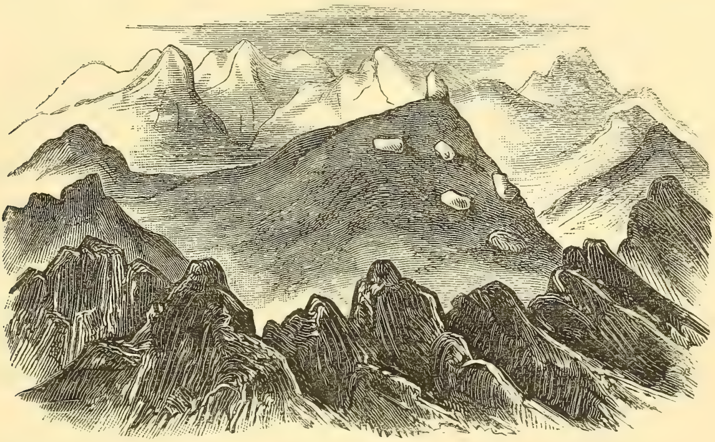
Glen Finnart.—Gneiss boulder about 7 feet high, 824 feet above sea, called "*Pulag*,"—butted against a rock at its south end. Reasons given why this boulder and others of smaller size appear to have come from north.

Firth of Clyde.—At Dunoon, Kirn, Innellan, Toward Lighthouse, and Loch Striven, there are numerous boulders, many of large size on and near the shore, some of them with local names and legends. They differ from adjoining rocks.

On east side of Firth, near *Gourock*, immense numbers of blocks, on or near the shore, belonging to rocks situated to the N.W. in the districts about Loch Goil, Loch Eck, Loch Fyne, and Inveraray.—("*Among the rocks around Glasgow*," 1881, by Dugald Bell, p. 152.)

Near Loch Glashan (400 feet above sea) smoothed and striated rocks, dipping down N.N.E. covered with boulders, apparently brought from N.E. where an opening among hills, towards Loch Awe (*Sixth Report*, p. 9) (*Lithograph* No. 6, Plate VIII.).

East Loch Tarbert.—About 2 miles N.W. of the town, a conical hill, whose top is 710 feet above sea, well clustered with boulders, as shown on annexed woodcut. Very summit of hill has one remark-



Boulders on Hill, East Tarbert, Kintyre.

able boulder on it, 8 feet high and 5 feet each way in width. The boulders are all *gneiss*, whilst rock of hill is *clay-slate.*

This hill separated from adjoining hills, which form a sort of amphitheatre round it, at a distance of about a mile.

The boulder has the fanciful gaelic name of *Capel Cloiche*, meaning *Stone Mare.*

Between the above-mentioned hill and the village of Tarbert, on south side of road, there is a lower hill, also conical, having two large boulders on its N.W. slope. Convener did not reach them to examine them.

On hills adjoining East Tarbert village on the south, at from 280 to 300 feet above sea, there are marks of some violent agent having

swept through the valley (now a sea loch) from westward (*Eighth Report*, pp. 4, 5).

On one of hills on north side of sea loch, and sloping down towards loch, a boulder found at height of 400 feet above sea. Boulder $7 \times 5 \times 3\frac{1}{2}$. Boulder apparently brought from S. or S.W. (*Ninth Report*, p. 3).

Crinan Valley.—Summit level between Loch Fyne and Crinan Bay, about 150 feet above sea.

At summit level, a ridge of rocks which present smoothed surfaces on *north*, but rough surfaces on *south* side of ridge. On both sides of ridge there are boulders, but ten times more on *north* than on *south* side.

Boulders are a syenitic gneiss, the rocks *in situ* a shivery clay slate; dipping steeply towards south.

Three or four boulders are butted or squeezed up against ridge on north side, apparently obstructed by ridge in their further progress southwards (*Seventh Report*, p. 4).

Ardchattan.—Granite boulder $14 \times 12 \times 6$ feet. One rut on its top running whole length. Height above sea 57 feet. Nearest rock of same nature is on Ben Breac, 3 miles eastward. Near boulder, a ridge of sand and gravel running $1\frac{1}{2}$ miles (*Reporter*, Captain White, R.E.).*

Loch Fyne.—Near *Loch Gair*, a boulder $23 \times 17 \times 12$ feet of coarse gneiss (286 tons), lying on a knoll of gravel in an amphitheatre surrounded by hills. Its longer axis N.N.E. and S.S.W.

Inveraray.—Boulder of porphyry, pointed out to Convener by Duke of Argyll, at height of 1000 feet above sea.

Boulder of coarse Conglomerate in same district, from 700 to 800 feet above sea, which probably came from westward, where rocks of Conglomerate are situated (*Fourth Report*, p. 10).

On summit of range of hills separating *Loch Fyne* and *Loch Awe*, about 1800 feet above sea, the rocks present a well-rounded and

* Whilst these sheets are being printed, the Convener has had the pleasure of receiving a communication from W. Anderson Smith of Ledaig (Argyleshire), enclosing for perusal and inspection a Memoir by him entitled "*Benderloch Boulders, along with fifteen sheets of Illustrations.*" Benderloch is the name of the district in Argyleshire situated between Lochs Etive and Creran, and in which the highest point is *Ben Breac*, 2338 feet. Mr Anderson Smith, in his letter accompanying the Memoir, mentioned that as it is intended to be read during the present session of the Glasgow Geological Society, he wishes it returned after the Convener has perused it, unless he wishes to bring it before

smooth surface. Direction of abrading forces there is from N.N.E. Remarked that, "in this case, glacier action impossible;" and that apparently the peak had been a rocky islet, on which floating icebergs drifted.

"On some of the lower ridges, towards Loch Fyne, there are remarkable examples of large blocks of granite perched upon the very summits, in positions which it is impossible to suppose them to have attained, by any other means than by transportation upon ice" (Duke of Argyll, *Proceedings of Royal Society of Edinburgh*, vol. iii. p. 457).

Loch Awe.—(1) About a mile south of Port Sonnachan, a perched boulder of compact gneiss, 13 × 12 × 6 feet, stands on a narrow ridge of soft mica schist, in a peculiarly precarious position. Its longer axis N. and S. Its height above sea 1026 feet. Sides of hill to the ridge, so steep, that Convener could with great difficulty climb up to the ridge. There being no higher hills near, supposed that boulder could have come only by floating ice, and from north, where there is the greatest opening (*Lithograph* No. 7, Plate VIII. (*Sixth Report*, p. 8).

(2) On hills to eastward, about 900 feet above sea, the slopes facing north are well covered by boulders. The largest, 18 × 10 × 10 feet (130 tons), has its longer axis lying N. and S. (*Sixth Report*, p. 10).

Brander, Pass of.—On its east side two terraces, at 68 and

his colleagues of the Boulder Committee, and that the Convener is free to refer to the paper in any way.

The Convener thinks very highly of Mr Anderson Smith's paper, and especially of the illustrations. But he does not feel justified in detaining it, as the meetings of the Glasgow Geological Society for the present session will probably soon terminate. The great value of Mr Anderson Smith's illustrations may be judged of even from the mere titles of a few of them.

(1) *Granite Boulder* (12 to 15 tons), a few feet from the top on northern face of a hill over Loch Creran; greatest diameter 10 feet N.W. and S.E.; smallest end N.W.

(2) *Boulder on Table land,* below the above (10 tons); N.W. and S.E.; smallest end N.W.

(3) *Black Granite Boulder* (10 tons); greatest diameter 8 feet, lying N.W. and S.E.; smallest end N.W.

(4) *Grey Granite Boulder,* over Barcaldine Gardens, 400 feet above sea, 19 × 12 × 7 feet; longest axis N.W. and S.E.

(5) *Grey Granite Boulder,* 300 feet above sea; 13 × 7 × 5 feet; longest diameter N. and S.

(6) *Ardchattan Boulder* (mentioned in this Committee's Report) is in one of the illustrations represented as partly buried in moss, and weighing about 50 tons.

120 feet respectively, above Loch Awe, with several boulders on each (*Fourth Report*, p. 9).

(3) Remarks of a general nature (p. 11) applicable to boulders at Dalmally and Tyndrum.

(4) Boulder 24 × 11 × 7 feet (136 tons), resting on a gravel knol on south bank of Loch Awe, at Kaim (west of Port Sonnachan). Boulder in a meadow surrounded by steep hills on all sides but one, viz., the West (*Sixth Report*, p. 11).

Between Port Sonnachan and Kaim, rocks smoothed and striated, seen on road side.

On the island of *Innisdraiodhnich* (Druid's Isle), in Loch Awe, a large boulder was reported to Convener by Mr Muir, the proprietor, but Convener was unable to visit the island (see notice in vol. vii. p. 226, of *Transactions of Society of Scotch Antiquaries*).

Ardrishaig—on Loch Gilp, a branch of Loch Fyne. On hills above town, boulders and striated rocks, suggesting transport from north; and in one case, transport through a lateral valley from N.W. (*Sixth Report*, p. 12).

On Auchendarroch lands, two large boulders seen, with N. and S. axis, lying on a hill slope facing S.E., at a height of 300 feet above the sea.

Ascending to a higher level, where hill slope faces N.N.E., several boulders found, of sizes not so great as the above.

All these appeared to have come from northern points.

Ach-na-briach (Field of Spots), near Loch Gilphead, visited to see sculptured cup or ring markings on smoothed rocks.

Rock surfaces evidently smoothed by natural agency. They are in different parts of field. All slope down at angle of 10° or 12° towards S.W.

One small boulder seen on west side of rocks, as if intercepted by rock in its progress eastwards. Difficult to say how or from what direction smoothings effected. May have been by heavy mantle of ice, sliding over rocks from hills to N.E.

The concentric ruts are numerous, and of various diameters and depths, some even 2 feet across. The straight rut issuing from centre and across circular ruts, generally, though not always, follows downwards slope of rock (*Ninth Report*, p. 10).

Loch Killesport.—A little to west of Ormsary House, on the shore, three very large boulders of gneiss, two weighing respectively

106 and 300 tons. Two have longer axis pointing N.W., the other with sharpest end pointing W.S.W.

About a quarter of a mile east of Ormsary House, a boulder, from which part at west end broken off. Before being broken, size was 52 × 36 × 20 feet, containing about 2770 tons;* lying on drift at the foot of old sea-bank, whose base is about 40 feet above sea-level.

In this part of coast an immense number of other boulders of different weights up to 400 tons, some touching or lying on others. They are mostly on slopes facing westward (*Lithograph* No. 8, Plate VIII.) (*Sixth Report*, p. 14, and *Ninth Report*, p. 4).

Valley of *Auchloss*, about 2 miles to east, shows smoothed rocks. The direction of valley is E. and W.; the direction of striæ W. by N.

In *Baronlongart Valley*, running E. and W. between Ormsary and Achloss, rocks ground down and smoothed, evidently from westward. A few boulders in valley.

(5) *Clach Briach Hill* (Stone Spotted Hill), about 400 feet above sea, well covered by boulders, many very large. Some so placed as to show they had probably come from N.W. Rounded on N.W. and rough on S.E. ends. Apparently all of same description of rock as "*Big Boulder*" before mentioned, a compact fine-grained gneiss. Rocks of hill, a soft schist, and on edge (Diagrams in *Ninth Report*, p. 4).

Fragments broken off S.E. ends of several large boulders, by some natural agency.

Two large boulders, 17 × 8 × 8 feet and 18 × 10 × 10, touching one another in such a way as to show that the last which came probably came from N.W.

Loch Sweyn—an arm of sea 10 miles west of Lochgilphead.

(1) At Keill, on north side of Loch, at mouth, several granite and gneiss boulders lie on the shore, and on slopes facing Jura Island, Rocks *in situ*, are dark coloured Silurian.

(2) In Carig Bay, near Lochgilphead, in north Knapdale parish, a boulder is on a hill slope facing N.W. and Jura Island.

(3) At Loch Mhurrich, a boulder 36 × 15 × 13 feet (520 tons), resting on a knoll of drift, in a meadow, surrounded by low hills;

* This boulder, first made known to Convener by Mr Campbell of Islay, who stated that it is the largest boulder he had seen or heard of in Scotland.

which are also well coated with boulders. Its longer axis, W.S.W. Its west end, 5 feet thick vertically; its east end, 12 feet thick vertically, must have come from westward, by an opening in the hills in that direction (*Sixth Report*, p. 16, and *Ninth Report*, p. 7).

(4) Numerous small lateral valleys opening on Loch Sweyn, the sides of which coated with boulders, these sides sloping down chiefly towards and facing W.N.W.

(5) *Kilmory Bay.*—Rocks smoothed and striated, with large boulders lying close at hand—their longer axis generally W.S.W. (*Seventh Report*, p. 10, and *Ninth Report*, p. 9).

The smoothed rock surfaces here dip down towards S. by E., South, S.S.E., and S.E. Where the rock slopes down S.E., the surface is not striated, only smoothed. The rock has been most severely striated on its surface sloping down S. and S. by E. Some of the striæ more deeply cut at one end than at the other, viz., at their west ends, where some as much as 3 inches wide. The striating agent had therefore moved from W. by S., or from due West.

Portions of the smoothed surface were broken into small cup-shaped hollows, containing hard pebbles firmly compacted,—probably samples of the tools which effected the striations (see *Ninth Report*, p. 9, and *Lithograph* No. 11, Plate VIII.).

The hill to the east consists of a ridge running about E. and W., and rising to a height of about 600 feet. Its north flank slopes steeply down towards Loch Sweyn, and is covered by boulders in immense numbers, and some of great size. The hill slope faces down N.N.W., but almost all the boulders lie with their longer axis pointing W.N.W.

About half a mile farther east, on a much steeper part of this hill slope, there is a cluster of huge boulders, the uppermost lying on the rest in such a way as to show it must have come from the westward (see *Ninth Report*, p. 10, and *Lithograph* No. 10, Plate VIII.).

Taynish.—(1) A large assemblage of boulders lying on rock of shore near Taynish House (property of Captain Campbell of Inverneil). Largest 18 × 11 × 8 feet, lies on broken edges of vertical strata. Longer axis lies W. by S.; and its narrowest end points west. There is another boulder 19 × 15 × 5 feet; its longer axis N.E. and S.W. Greatest number of boulders lie on rocky slope facing north-westerly.

Several other large boulders near Taynish House reported, but not seen.

(2) On each side of road to Ardrishaig, many boulders observed;—occupying chiefly north-westerly hill slopes.

(3) Near Crinan Canal at *Ballanach*, about $\frac{1}{2}$ mile from canal, at 300 feet above sea, boulder, $16 \times 9 \times 9$, on north side of valley. It lies on bared rocks. Its longer axis coincides with axis of valley, viz., S.W. by S. (*Ninth Report*, p. 8).

Numbers of large boulders lie on hills to eastward, chiefly on slopes facing N.W.—(Diagram given in *Ninth Report.*)

(4) *Dana, Island of.*—On the shore of this island, forming the

Dana Boulder.

north bank of Loch Sweyn, and nearly opposite Castle Sweyn, there is on the shore a boulder weighing from 70 to 80 tons (see prefixed woodcut). Its sharpest end is towards west, and longest axis parallel with the axis of the loch (*Seventh Report*, p. 12).

On the south bank of loch here, there is a projecting mass of rock on which Castle Sweyn has been built. On the west side of this rocky mass, a number of boulders lie, as if intercepted by the rock in their progress from the west. The narrowest part of the Loch is here; so that on this account there is the more probability of blockage having occurred at this point.

Oban and Neighbourhood.—(1) Grey granite boulder $12 \times 8 \times 6$ feet at Dunolly. Nearest granite rocks are on Loch Etive, to eastward, but doubted whether of same variety. The boulder is at foot of a cliff of Conglomerate rock.

(2) A mass of Conglomerate rock above the town, well rounded. On the side facing N.W. the hard pebbles are all ground down; on east side the pebbles of the rock are rough.

(3) *Oban.*—At south end of town, there are cliffs of old conglomerate rock, from which blocks have been carried southwards and are strewn on a meadow to a distance of from 100 to 200 yards from the cliffs (*Seventh Report*, p. 4).

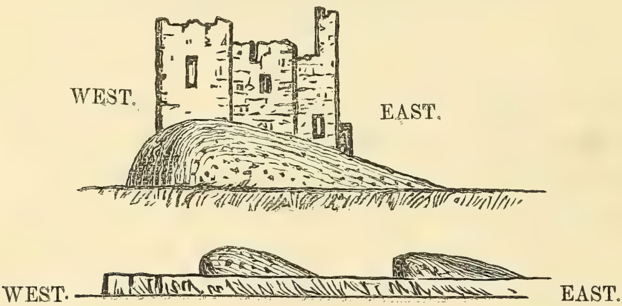
A plan given to show where these boulders situated, many being on hill slopes facing N. and N.W. These boulders are mostly all grey granite.

On the hills, near Professor Blackie's cottage, there are several large grey granite boulders on slopes facing N. and N.W.

On small island in Oban Bay, several grey granite boulders, so situated, as to show transport from north (*Seventh Report*, p. 7).

On the farm of Dunbeg, near Connal Ferry, a boulder of grey granite lying on rocks of clay-slate, in a position showing transport from N.W. (*Seventh Report*, p. 8).

At Dunstaffnage, about 5 miles N.E. of Oban, the rocks smoothed in such a way as to suggest movement over them of an agent from *eastward*, viz., down Loch Etive. Along the shore, up towards Loch Awe, there are rocks similarly smoothed, as shown on the annexed woodcuts.



Rocks smoothed from Eastward in Loch Etive.

(4) At "Lailt," a dark porphyry boulder called "*Clach-a-Currail*" (*i.e.*, *perched boulder*), from its precarious position. Differs from all the rocks in district. Remains of a granite boulder also here.

(5) *Glenlonan.*—Several boulders, at heights of from 1600 to 1700 feet, of various kinds of rocks. Boulders are on both sides of summit level, but the greater number are on slopes facing the north, and the smoothed rocks also chiefly face the north.

(6) *Loch Etive.*—At Airde Point, many boulders on slopes look-

ing up towards Loch Awe and Ben Cruachan, as if brought by glacier; but they might also have come from north by floating ice.

Rocks on south shore of loch, above and below Connell Ferry, showing smoothings, strongly indicative of glacier from head of loch.

Angular grey granite boulder, 11 × 9 × 7 feet, above Bonawe Ferry at Innerlievern.

(7) *Kerrera, Island of.*—Numerous grey granite boulders on beach at north end of island; so placed, as to show transport from the north. Granite boulders with red tinge, found on Ballimore farm at from 350 to 440 feet above sea; but no granite rocks on island. Nearest place where such granite known is at Morven, about 12 miles across the sea to the north. The Mull granite said to be different.

On the farm of *Bal-na-Bck*, about 20 boulders seen by Convener, all granite except one.

(8) *Easdale.*—Many grey granite boulders lying on blue clay slate rocks. Supposed to have come from Mull Island, it being nearest place for such granite; and no obstruction in that direction.

One clay stone boulder of a purple colour was found;—said that rock of this character exists to the south.

(9) *Ben Cruachan* ascended to height of 2725 feet. Until contour of 1335 reached, few boulders seen. Above that, very numerous on N.W. shoulder of hill. Towards N.W. less obstruction to transport, than from any other quarter. Towards W.N.W and N.W. no hills, but those in Mull and Ardnamurchan, distant 30 to 40 miles.

Boulders are of red and grey granite. The sizes of four or five of largest given. The rocks of Cruachan, where these boulders lay, are chiefly a red granite.

Longer axis of boulders and rock striæ generally point N.W.

At heights of 334 feet and less, rocks appeared to have been smoothed from W.S.W., as if by glacier from Loch Awe. Above that height, the direction of the striæ is N.W. by N., N.N.W., and W.N.W., the last being most persistent in the highest parts of the hill. Some of these Cruachan boulders lie on beds of gravel, up to a height of 2000 feet (*Fifth Report*, p. 48).

Lismore, Island of.—Boulders of granite, red and grey, lie on the Limestone rocks. Old sea terrace well marked on island.

Appin.—On the shore of Linnhe Loch, two granite boulders, one

$20 \times 18 \times 11$ feet (292 tons), the other $15 \times 11 \times 10$ feet (122 tons), differing from adjoining rocks, which are clay slate (*First Report*, p. 26).

Loch Creran.—At Fasnacloich, boulders of black granite, two of 380 and 280 tons respectively. The boulders have their sharpest ends pointing towards mouth of Loch Creran, viz., to S.W. The rocks *in situ* are different.

Chips from these boulders having been submitted by the Convener to Professor Judd (Kensington Department), he identified them as similar in composition to rocks seen by him in Skye, Mull, and Ardnamurchan. It appeared to him that the Appin boulders, before mentioned, were the same in composition as the Fasnacloich boulders.

Professor Judd stated, that these Loch Creran and Appin boulders are not granites, but "rocks of a basic composition,—a gabbro with some black mica" (*Fourth Report*, p. 11).

At mouth of loch, rocks smoothed (when facing W.N.W.) up to about 70 feet above sea. About a mile higher up loch, smoothed rocks face W.S.W. at height of 80 feet above sea.

Near sea level, smoothing seemed due to some force moving down valley. Rocks at a higher level seemed to have been smoothed by force moving from N.W.

In Glen Creran most of boulders lie on *drift*. At one place boulders form a cluster on a rocky knoll.

Statement by Mr Hall, an intelligent residenter, that a *trainée* of boulders is traceable from Glen Creran through Carroban Pass, situated on S.E. part of Glen Creran (*Fifth Report*).

Ayrshire.

Coylton.—Granite boulder $11 \times 7\frac{1}{2} \times 5$ feet. Longer axis N. and S. There are four more boulders, weighing respectively 4, 8, and 12 tons, and form a line running N. and S. Legend that King Coil dined on large boulder (*First Report*, p. 28).

Dailly.—Granite boulder about 36 tons on Killochan estate, called "Baron's Stone," about 100 feet above sea. Lies on Silurian rocks; various other granite boulders south of River Girvan, on hill slopes. One on Maxwelton Farm, contains 240 cubic feet. Another on top of Barony Hill above Lannistane, 1047 feet above sea (*First Report*, p. 28).

Doune Loch.—Two miles south of, granite boulder called "*The Kirkstane,*" 25 × 20 × 12 feet (444 tons), so called because used as a pulpit for preaching from (*First Report*, p. 29).

Girvan.—Thousands of granite boulders and some whinstone boulders, for miles along the shore near Turnberry Point. Rocks *in situ* are sandstone. Nearest granite rocks are in Arran.

Along coast 4 miles south, in a ravine, two boulders of altered greywacke; one weighing 180 tons, the other 100 tons (*First Report*, p. 29).

Kilwinning.—On Misk Farm a pit was sunk for coal through boulder clay. Boulder of dolerite and a flint nodule found, at depth of 23 feet from surface. Flint was $3\frac{1}{4}$ inches in diameter and $2\frac{1}{2}$ inches thick. Dolerite was water-worn and roughly scratched. A flint nodule found on Inchlonaig, an island in Loch Lomond, in boulder clay, with arctic shells (Letter to Convener from Rev. David Robertson, Glasgow, dated 10th November 1876).*

Maybole.—Granite boulder, flat and oblong, on slope of hill above River Doon, on Auchindrane, at height of 230 feet above sea, known as Wallace's Stone, from tradition that a rude cross now carved on it represents his sword [Notes of cases from Dailly, Girvan, and Maybole, sent by Professor Geikie] (*First Report*, p. 29).

Ardrossan.—Near Hunterston on the shore, boulder of grey compact granite 11 × 6 × $5\frac{1}{2}$ feet and $26\frac{1}{2}$ feet in girth, opposite to great Cumbrae Island and about 12 miles from Arran (*Second Report*, p. 149).

On the shore about 2 miles to N.W. of Ardrossan, the "*Boydstone*" boulder of porphyry, about 19 × 19 feet (about 320 tons), on property belonging to Mr Alexander. Rocks here are Old Red Sandstone. Boulder partly buried in mud of the shore, but about 9 feet in height visible.

Two other boulders on Mr Alexander's property, one of them even larger than the foregoing,—of gneiss (*Second Report*, p. 149, *Third Report*, p. 3).

Stinchar Valley.—Boulder of claystone a cubic yard in size lies near hamlet of Poundland. Seemed identical in mineralogical

* In vol. vi. part 2, of Glasgow Geological Society's *Transactions*, pp. 186–190, notices will be found of flint nodules found on various other parts of the Ayrshire coast.

character with rock of Glassal Hill situated to N.E., and also with rock on shore to west at Bennane Head (*Sixth Report*, p. 33).

Culmonell.—Half a mile to north, at height of about 200 feet above sea, a dolerite boulder 27 × 23 × 12 feet (552 tons), its longer axis N. and S. It lies on till. A small boulder, apparently a fragment of large boulder, lies to the south (*Sixth Report*, p. 33).

Another boulder of dolerite, which had been 21 × 21 × 10 feet (326 tons), with longer axis N. and S.;—now rent into fragments. *Query.*—Did boulder break by falling from a height?

Lendalfoot.—A little to north, an Old Red Sandstone Conglomerate boulder 8 × 6 × 6 feet. It is undistinguishable from the Conglomerate rock of Wemyss Bay, situated about 30 miles to the north (*Sixth Report*, p. 33).

Beith.—On Cuffs Hill, consisting of porphyry, there are on its north side many small granite blocks which must have come from the west or N.W.

(1) Mr Robert Craig of Beith, in several papers read before the Geological Society of Glasgow (*Trans.*, vol. iv. parts 1 and 2), divides the boulders in the north of Aryshire into two classes. One class consists of rocks foreign to the district, viz., Old Red Sandstone, granite, quartz, gneiss, mica of chlorite, schists, and clay slate. These he thinks were transported from mountains in the N.W., distant from 50 to 70 miles, by drift ice and marine agency. The other class he derives from rocks situated to the N.E. and at no great distance, transported by land ice.

(2) Messrs Crosskey and Robertson also sent to the Glasgow Geological Society (*Trans.*, vol. iv. part 1) an account of boulders of great size, and in large numbers, found in excavating new docks at Greenock. The great majority of the larger boulders are sandstones of the neighbourhood;—the remainder are of quartz, mica schist, &c., from the Argyleshire mountains to the N.W.

(3) Mr Robertson, in the Glasgow Geological Society's *Transactions*, 19th Jan. 1877, gives an account of large boulders, covered with *Balani* and *Serpulæ*, in a bed of sandy mud 18 feet deep, containing also nodules of flint.

The conclusions he drew from the boulder being covered with marine zoophytes was, that after being so covered, they had been lifted up by shore ice and transported to their present position.

Banffshire.

Banff.—Between Banff and Peterhead, beds of glacial clay, similar to that of Caithness, and probably drifted from thence (*First Report*, p. 29).

Near Peterhead, many boulders of granite and trap, one of these of a greenish colour, not known *in situ* in Aberdeenshire, but occurs in Caithness (Jamieson, *Lond. Geol. Soc. Jour.*, xxii. p. 272).

Boyndie.—Hypersthene boulders found along shore for some miles. Supposed to have come from rocks to S.E. (*First Report*, p. 29).

Fordyce.—A line of boulders through several parishes in a S. and N. direction. They are a blue whinstone. In Ordiquhill parish, so close as to touch. Height above sea 500 feet (*First Report*, p. 29).

Berwickshire.

Berwick.—On *Castle Terrace*, boulder clay excavated for water pipes. Many boulders found in clay bed, of granite, gneiss, limestone, blue whinstone, greywacke, &c., all rounded. The granites showed two varieties, grey and red. Nearest granite hill is Cockburn Law, about 30 miles to N.W.;—nearest blue whinstone in rock, is about 25 miles to west (*Second Report*, p. 149).

Berwick.—About half a mile to north of the town, four boulders pointed out to Convener by Captain Norman, R.N., on side of a road leading to Halidon Hill. The boulders are each from half a ton to a ton in weight. Two are of fine grained granite,—one grey in colour, the other with a shade of pink.

The other two boulders are a dark porphyry;—the nearest locality for which is Lamberton Hill, situated about 2 miles to N. and N.N.W. (*Seventh Report*, p. 13).

Burnmouth.—Near railway station, in a gravel bed over greywacke rocks, a well rounded block of pinkish granite found by Convener.

He sent a chip to Mr Macdonald, granite worker, Aberdeen. He answered that it was a rare variety of granite. He knew of its existence *in situ*, only at Kincardine O'Neil (Deeside) and about Ballatar and Braemar, in the form of boulders, and as a rock in the Island of Uist (Hebrides) (*Second Report*, p. 149).

Coldstream.—A block of white chert limestone, about 4 feet square, very irregular in shape, found in a gravel bed at the Hirsel (the Earl of Home's).

The only place where rocks *in situ* of this nature found, is on the opposite, *i.e.*, the south side of the Tweed, at Carham and Nottylees, distant from Hirsel 3 or 4 miles, and bearing W. by S. (*Second Report*, p. 150).

Duns.—On farm of Cockburn, 2 miles N.N.W. of Duns, a boulder of mica schist, from 2 to 3 feet in length and breadth, lying at base of a steep hill facing the south. No mica schist rocks in Berwickshire, or nearer than the Grampians (*Second Report*, p. 150).

Foulden.—Several small boulders of coarse syenite, lying on Old Red Sandstone, composed of red felspar, black hornblende, and small flakes of mica; largest boulder is $5 \times 3\frac{1}{2} \times 2$ feet. Sharpest end points N.W.

Nearest hill where similar rocks occur is Cockburn Law, 8 miles to N.W. (*Second Report*, p. 150).

Greenlaw.—At Marchmont (residence of Sir Hugh Hume Campbell) about 930 feet above sea, a blue whinstone boulder $9\frac{1}{2} \times 5 \times 4\frac{1}{2}$ feet, with faint striæ on top, parallel with longer axis. Rocks *in situ*, Old Red Sandstone. Nearest whinstone rocks are in Gordon parish, 5 miles to west (*Second Report*, p. 150).

Gavinton.—Boulder clay 10 to 12 feet deep, covered by beds of gravel and sand, in some places 12 feet thick. In the clay, the boulders composed of rocks recognised as occurring *in situ* in localities W. by N., as at Kyles Hill and Dirrington,—these hills being from 3 to 6 miles distant (*Fourth Report*, p. 20).

Ayton Parish.—Several small boulders of grey granite, 270 feet above sea, on Whitfield farm. Nearest granite hill, Cockburn Law, 10 miles W.N.W.

Near Ayton Castle, pieces of coal found in deep bed of sand, about 200 feet above sea. Coal strata occur in Mid-Lothian on north side of Lammermuir Hills, 40 miles to N.W. (*Sixth Report*, p. 17).

Coldingham Parish.—On Cocklaw Farm, well rounded masses of hematite ore found, turned up by plough, at height of 500 feet above sea. Nearest place where hematite known is in East Lothian, about 30 miles to N.W.

On the same farm, blocks of white sandstone found, which is not known to be *in situ* nearer than East Lothian (*Sixth Report*, p. 17).

On the rocks near Coldingham Loch, and at St Abb's Head, the striæ on the lochs show a movement from N. by W. (Ed. *R. S. Tr.*, vol. xxvii. p. 36).

Chirnside Parish.—On Oldcastle Farm, numerous boulders of grey granite, from one to two tons in weight and 300 feet above sea. Nearest granite hill is Cockburn Law and Stenchel, about 8 miles to N.W. (*Sixth Report*, p. 17).

Edrom Parish.—At Blackadder, a boulder of blue whinstone on knoll of gravel, about 250 feet above sea. Nearest rock of same kind is at Hardens, 5 miles to N.W., which is 500 feet above sea.

Hutton Parish.—In Paxton brickwork, blue whinstone boulder found $7\frac{1}{2} \times 4\frac{1}{2} \times 3$ feet, weighing about 10 tons, with striæ on one of its sides parallel with longer axis. Its longer axis N.W. by N., about 230 feet above sea. In that direction only there is whinstone rock *in situ*, viz., Borthwick Hill, situated 12 miles to N.N.W., about 600 feet above sea. At same brickwork, in a bed of boulder clay, small boulders of red conglomerate, greywacke, and chert found; also the brick-coloured porphyries of Kyles Hill and Dirrington, situated from 14 to 16 miles to westward. The whinstone boulder taken by Convener into Paxton Policy for preservation.

Blocks of same blue whinstone occur on adjoining lands of Broadmeadows and Sunwick.

Blocks of a very peculiar crystalline greywacke, with cavities, and of a black colour, occur in Pistol Plantations (Edrom parish). The only locality in Berwickshire for this rock is in the channel of the River Whitadder, east of Cockburn Law, at a distance of 12 miles N.W. Blocks of the same rock are found on the farms which lie between Pistol Plantations and Cockburn Law (*Sixth Report*, p. 18).

Stitchel Parish.—Pebbles of Old Red Sandstone lying on blue whinstone rocks at Stitchel Craggs, at 600 feet above sea. Nearest place where Red Sandstone strata known is some miles to west (*Sixth Report*, p. 18).

On west sides of those craggs, smoothed surfaces of whinstone dipping towards or facing W.N.W. (*Sixth Report*, p. 18).

At Baillie Knowe in same parish, 300 feet above sea, a whinstone hill, with similar smoothed surfaces, fronting W.N.W.

On Smailholm Craggs (3 miles west of Stitchell) at 570 feet above sea, rocks facing W.N.W. show striæ by an agent moving from W.S.W.

Earlston Parish.—Blocks of felspar porphyry, from Cowden-

knows Hill, strewed over muirs to east, resting on Old Red Sandstone strata (*Sixth Report*, p. 18).

Hume Parish.—Rocks on craggs there at 740 feet above sea, smoothed and striated in E. and W. directions (*Sixth Report*, p. 19).

(For other cases in Berwickshire, see paper by Mr Stevenson, in *Berw. Nat. Club. Trans.*, vol. vii. p. 20.)

Mordington.—A block of very coarse-grained syenite found near top of Halidon Hill, on a slope facing west, at a height of about 400 feet above sea. The only hill in Berwickshire where syenite rock occurs is the Stenchel, on east side of Cockburn Law, about 10 miles to W.N.W.

The Convener submitted a specimen of the block to the late Mr Stevenson of Duns, who was a good geologist, and well acquainted with Berwickshire rocks. He was of opinion that the block closely resembled a syenite which he had seen in Mull (*Ninth Report*, p. 11).

Kaims.—In different parts of this county there are numerous examples of Kaims. One on Greenlaw Muir is continuous for nearly 2 miles. They are numerous also in the lower districts, and are there more or less parallel to one another, and to the general axis of the Tweed valley. The average direction near Kelso is N.E. by N. ;—in the east part of the county the average direction is E. 10° S. (Ed. *R. S. Tr.*, vol. xxvii. p. 29).

Buteshire.

Big Cumbrae Island.—Many boulders of mica schist lying on Old Red Sandstone rocks of island. Largest boulder seen 12 × 6 × 3 feet, with longer axis N.N.E. lying in valley running N.N.E. at north end of island. Mica schist boulders occur also at S.W. end of island (*Second Report*, p. 151, and *Sixth Report*, p. 24).

Little Cumbrae Island.—On highest part of island, about 400 feet above sea, rocks *in situ* (claystone trap) sloping down towards N.W., have been smoothed by some heavy agent passing over them, from N. by W. Several boulders of Old Red Conglomerate found. The largest is about 5 feet square and rests on rock, with so small a basis that it can be rocked, known by the name of "*Bell Stane*." Rev. Mr Lytteil suggested to Convener that name may have been originally "*Beltane*," on account of fires lighted on it in Pagan times. Close

to this block there is another Conglomerate boulder of smaller size, with an ancient cup-shape hollow on its surface, apparently artificial, 4 inches in diameter and $\frac{1}{2}$ inch deep. Height above sea 190 feet (*Sixth Report*, p. 25).

No Old Red or Conglomerate *rocks* in island. Nearest are at Toward Point and Rothesay, from 12 to 20 miles across the sea to N.W.

"*Split Boulder*," first mentioned by Smith of Jordanhill, visited. Lies at sea-level, on rocks much smoothed and striated, forming east side of a trough, axis of which runs N.E. by N. Some of the striæ are continuous for 30 yards. Striating agent must have moved from due north (*Sixth Report*, p. 25).

Ailsa Craig, a mass of white porphyry, reaches to a height of 1114 feet. At a height of 600 feet, on north side, there is a bed of clay mixed with sand of a red colour, derived probably from the débris of the Old Red Sandstone rocks of Arran, Big Cumbrae, Rothesay, and Toward;—all situated to the N. and N.W. Pebbles of granite and quartz said to have been seen on the Craig (*Sixth Boulder Report*, p. 23).

Arran, Island of.—(1) In *Brodick Bay* (East Coast), no boulders; but along coast, to north and also to south, numerous and large boulders.

Corriegill.—Boulder of grey granite, has longer axis and sharp end to N.W. Same kind of granite in Goatfell mountain, distant 4 miles bearing N.N.W.

Another boulder, 12 × 9 × 8 feet, half a mile to north, has its longer axis N. and S.

(2) Near *Corrie*, two large boulders of granite sit near each other on plateau or terrace, about 93 feet above sea. Largest may weigh about 620 tons. Longer axis and sharpest end point N. by W. Rock on which it lies is Carboniferous sandstone. These two boulders must have been *carried*,—there being no adjoining hill rom which they could fall. Goatfell bears from them W. by S., and is distant about 3 miles. By a glacier they could not have been carried, as they are not in a valley, or near any valley from which a glacier could have issued (*Sixth Report*, p. 21).

(3) To the north of *Corrie*, about 2 miles, the road passes a large boulder on the sea-shore called the "*Catstane*," whose weight is estimated at 362 tons.

Near this boulder there is a granite boulder, with a weight of about 212 tons. Its longer axis lies N. and S., the narrowest end being to the north.

(4) There is another granite boulder on the old sea-beach, at a height of 12 feet above high water. It rests on Conglomerate strata, which dip towards the south. It is blocked at south end, by a knob of Conglomerate rock, which seems to have obstructed it in its progress from the north (see Diagram in *Sixth Report*, pl. xix. fig. 5; also *Lithograph* No. 9, Plate VIII.).

Many blocks of this Conglomerate Sandstone have been carried along the shore southwards;—none found to the north.

(5) On the hills west of Corrie there are rocks with striæ on smoothed surfaces at a height of 158 feet above sea. The direction of the striæ is N.W. and S E.

On these hills, up to 587 feet above the sea, there are many boulders,—mostly of grey granite, and a few of Conglomerate.

Between those hills and Goatfell there is a deep valley, well strewed with granite blocks. Most of them are rounded. On west side of valley, hill climbed to a height of about 1270 feet. One boulder attracted attention, being 23 feet long 9 feet wide and 12 feet high (184 tons). This, and many others, lay with longer axis N. and S. Its position showed that it had not fallen from any hill, and must have been *carried* to its present site.

(6) In crossing to *Loch Ranza*, Convener saw to the south of the high road numerous "*perched*" blocks on the tops and ridges of the hills at heights of from 1506 to 2000 feet above the sea. He regretted not being able to examine them. They were most numerous on hill slopes facing N.W.

The absence of boulders in Brodick Bay, whilst they abound along the shore to the north and south, invites special explanation. If a glacier descended from Goatfell, boulders should have been numerous in the bay and valley leading up from it to Goatfell. If the boulders came on floating ice from the N. or N.N.E. they would be dropped along the east shore, and on the hill slopes facing the north. But they would be deflected from Brodick Bay, by a high ridge of rocks which comes down from Goatfell to the north of Brodick Bay (*Sixth Report*, p. 22).

(7) Beds of fine clay in south end of Arran (first described by

Rev. Mr Watson) contain Arctic shells, sometimes in a broken or crushed state. This fossiliferous stratum is covered by a great thickness, of what Mr Watson calls *boulder clay*, but which Messrs Bryce and Croskey call *upper drift beds.* The upper stuff also contains broken shells (*Jamieson in paper published in Proceedings of London Geological Society* of February 1866, p. 276).

Bute Island.—East coast, north of Rothesay, examined, and a list of boulders found there given. They consist chiefly of schists lying on Old Red Sandstone and clay slate rocks,—and must have come from the hills to the north (*Seventh Report*, p. 14).

Along west coast, north of Ettrick Bay, there are numerous boulders, also of schists, which show by their positions that they also came from north. Several of these boulders are standing on end leaning against rocks on their east sides (*Seventh Report*, p. 16) (*Lithograph* No. 12, Plate VIII.).

Barone Hill, situated about 3 miles S.W. of Rothesay, at a height above the sea of about 500 feet, has at its west end a rocky gorge with remarkable striæ on sides, which indicate passage through gorge of a powerful current of some kind, hurrying through it from a northerly point, stones and rubbish. A diagram given of some of the striæ, showing that they have been incised more deeply at north ends than elsewhere, in consequence probably of the pebbles becoming blunted by friction by being squeezed against the rock.

This spot is referred to in a paper " On Glacial Drift in Scotland," by Professor Geikie, who gives it as his opinion that " the abrasion (of these Barone Hill rocks) has been done by an agent, which came up the steep northern face of that eminence, went right over its summit, and pursued its course down into the next valley beyond. The striations (the Professor adds) run from N. 15° W. to N. 20° E." (*Seventh Report*, p. 20) (*Lithograph* No. 13, Plate VIII.).

Caithness.

Dunnet.—Conglomerate boulder of small size, apparently from Maiden Pap Hill, 30 miles to south. Several large boulders in parishes of Olrich and Cannesby (*First Report*, p. 29).

Thurso.—Near Castletown, large granite boulder. Between Wey-

darle and Stonegun, several large Conglomerate boulders. Rev. Mr Joass, of Golspie, states that nearest granite and Conglomerate rocks in the county are situated in N.W. districts (*First Report*, p. 30).

Keiss Parish.—Conglomerate boulder 9 × 7 × 5 feet called "*Grey Stone.*" Longest axis W. by N. Differs from any rock in locality. It marked, where it stood, boundary between two parishes and two estates. It has lately been blasted into four fragments, of which three still remain (*Eighth Report*, p. 8).

Mr Jamieson of Ellon, having examined *Keiss Harbour*, states that a bed of "drift," 40 feet thick is there, the lower half of which consists of unstratified sandy mud, containing broken shells and stones, some of which are scratched. The scratches and grooves point N. 35° to 40° W.

Scrabster Harbour.—Mr Jamieson reports that here the boulder clay is more than 100 feet thick. It is charged with small stones more or less rubbed and scratched. He found in it fragments of shells.

Wick.—Three boulders, each weighing from 20 to 30 tons. One is a Conglomerate, supposed to have come from hills 20 miles to south. But Rev. Mr Joass states that Conglomerate rock occurs to westward at less distance.

Wick Bay.—Mr Jamieson found here a similar bed of boulder clay, containing fragments of shells and numerous large water-worn boulders of sandstone, quartzose, mica slate, and granite, on which glacial scorings are well marked. One granite boulder was 12 feet in length (*First Report*, p. 30, and *Proceedings of London Geological Society*, 7th February 1866, p. 265).

In the same paper, Mr Jamieson states that in Caithness generally, the shells, as a rule, in the clay beds and drift, are broken. But exceptions occur. He himself found one entire valve of *Astarte Borealis;* and he saw several entire specimens in local collections.

He adds, that one of the objects he "had particularly in view was to note the direction of the glacial markings on the rocks, and to ascertain whether they could be accounted for by a movement of ice proceeding from the interior of the country towards the coast. I therefore lost no opportunity of noting the bearings of

scratches whenever I saw them." Mr Jamieson then gives the bearings at twenty localities in Caithness, from which he concludes that the movement had been from N.W. to S.E.; and he adds, that "a movement of ice from N.W. to S.E. across Caithness is totally at variance with the notion of the scratches having been caused by glacier action proceeding from the interior of the country towards the present coast." In a footnote, Mr Jamieson adds, that "the presence of marine organisms (in the Caithness drift), and the direction of the glacial striæ, which indicate a movement from the N.W., *where there is now nothing but open sea* for an immense distance, together with the absence of moraines, are all suggestive of *marine conditions having prevailed during the deposition of the Caithness drift.*"

In year 1828, the late Sir Roderick Murchison published a paper in *Proceedings of London Geological Society*, in which he mentions that "the highest hills in the *Brora* district afford, upon their sides and summits, distinct traces of a strong diluvial current, which has swept them free of covering matter, and deposited in the plain of Clyne, Milltown, a mass composed of the debris of the denuded hills. A large portion of the turf having been recently removed, the surface of the rock was seen to be scored with parallel lines. The direction of the markings is uniformly from N.N.W. to S.S.E."

Dumbartonshire.

Luss.—On west bank of Loch Lomond, about 150 feet above sea, in channel of a brook entering *Fruin Water*, a *mica schist* boulder 28 × 18 × 7 feet (246 tons). Longer axis E. and W., with sharp end to west. Rocks adjoining—Old Red Sandstone. Nearest mica schist hills about 5 miles to N. and W. If boulder came from that direction, it must have been carried across hills from 1000 to 2000 feet high. If it came from north, down Loch Lomond valley, it must, after coming so far, have changed its course and moved at right angles to westward to gain its present site (*Second Report*, p. 153, *Fourth Report*, p. 20).

On a moor, about half a mile to N.E. of the above boulder, there are several smaller boulders of mica schist, all with longer axis in similar direction, viz., east and west.

On west side of Loch Lomond, at *Arden*, a low valley running

up from loch, shows many small boulders,—their longer axis and sharpest ends pointing N.W. (*Fourth Report*, p. 21, *Sixth Report*, p. 6).

On east bank of Loch Lomond, nearly opposite to Arden, at about 337 feet above sea, a grey granite boulder $5 \times 4 \times 4$ feet, much rounded—lying on Old Red Sandstone strata. Longer axis E. and W.;—it had probably crossed loch, from west (*Sixth Report*, p. 7).

In Cameron House Policy, gneiss boulder $6\frac{1}{2} \times 5 \times 5$ feet, with longer axis N.W. and S.E.

About 3 miles to S.W. of the south end of Loch Lomond there is a hill called "*Caer-man*," reaching to height of 720 feet above sea. Rocks on top are a coarse porphyry. The rocks on western aspects are well rounded;—on eastern aspect, the rocks are rough. There are huge fragments on east side of top, none on west side (*Fourth Report*, p. 21).

DUMFRIESSHIRE.

Kirkconnel.—Granite boulder, 7 feet in diameter, 20 to 30 tons, 700 feet above sea. Differs from adjoining rocks. No granite rock nearer than Spango Water (*First Report*, p. 30).

Tynron.—Three whinstone boulders, each weighing from 20 to 30 tons, also several Conglomerate boulders;—all have apparently come from N.W. (*First Report*, p. 30).

Wamphray.—Large whinstone boulder (*First Report*, p. 36).

Moffat.—Several large perched boulders near *Loch Skene*, at height of 1900 feet above sea—(*Mr Ralph Richardson inferred that they were "transported by a local glacier"*)—(*Seventh Report*, p. 28).

(See notes regarding these boulders, by Convener, in the *Transactions of the Edinburgh Geological Society* for May 1881.)

Langholm.—In Wauchope valley, and also in bed of that river, granite boulder $16 \times 11 \times 6\frac{1}{2}$ feet, weighing from 50 to 70 tons, lying on Sandstone rocks. Many others scattered about (*W. Strachan Schoolmaster, Langholm*).

Cairnsmore of Fleet, a hill 2331 feet high, situated in Kirkcudbrightshire;—composed of coarse grey granite.—"Boulders of Cairnsmore granite are scattered over the hills to the S.E. One is on the west face of the Nether Hill, at the height of 1100 feet, and 8 miles distant from its source" (*Survey of Dumfriesshire by Scotch Government Surveyors in Memoir*, No. 9, p. 39).

(*Extract from the Fourth Report of the Boulder Committee of British Association*) :—Professor Harkness mentions a boulder of Silurian Conglomerate at the village of Bothal, North Cumberland, 20 × 9 × 5 feet. It is striated on its western side. It is between 400 and 500 feet above sea-level, and, in his opinion, *was transported from Dumfriesshire*, having therefore travelled about 40 miles from N.N.W.

Elgin.

Dallas.—Many small granite boulders here, which are supposed to have come from Ross-shire (*First Report*, p. 31).

Duffus.—Conglomerate boulder 21 × 14 × 4 feet, longer axis N.W., on Roseisle estate (*First Report*, p. 31).

Llanbryde, St Andrews.—Gneiss boulder in bed of Old Spynie Loch, 15 × 9 × 7 feet, longer axis N.N.E.

New Spynie.—Four Conglomerate boulders lying on Old Red Sandstone rock (*First Report*, p. 31).

Rothes.—Six horneblende boulders lying on gneiss rocks.

Dyke.—Near Darnaway Castle, in the approach to, several granite and gneiss boulders from 2 to 3 tons.

A kaim $\frac{1}{4}$ mile long, running N. and S. (*Second Report*, p. 152).

Elgin.—Boulder called " *Carlin's Stone*," on Bogton Farm, a coarse Conglomerate 230 feet above sea, with pebbles of flesh-coloured quartzite. About half a mile to N.W. another Conglomerate boulder, called " *Young Carlin's Stone.*"

Hundreds of smaller boulders of granite, gneiss, &c., embedded in clay or sand, which seems to have been pushed or rolled, being all well rounded.

Carden Hill has been ground down and striated. Direction of striæ varies between W. by N. and N.W. Numerous boulders on ridge of hill, and on both sides of it.

At several places on ridge, rocks broken up, and fragments pushed over southern slope.

At one spot on Carden Hill, the N.W. striæ crossed by others from N.E.

Quarrywood Hill, composed of Sandstone rocks, has four or five large Conglomerate boulders on its N.W. slope.

Forres.—Conglomerate boulder on Upper Caliper Farm, about 44 tons, lies on hill-side facing Cromarty, which bears N.W. by N. 10 miles across Moray Firth. Another Conglomerate boulder on same farm, much buried in drift. These boulders contain reddish quartzite pebbles.

Forres to Nairn.—Extensive beds of sand and gravel, mostly stratified. Pebbles and boulders in these beds well-rounded; angular boulders chiefly on surface (*Second Report*, p. 155).

Lossiemouth.—On old sea margin, Conglomerate boulders of same character as those in other parishes.

In boulder clay over Limestone rocks, boulders of oolite found, which must have come from Ross or Sutherland.

Portions of an oolite boulder seen by Convener, near Duffus Schoolhouse, 125 feet above sea.

Conglomerate boulder, called "*Witch-stone*," similar to all the others. Longer axis N.W., and sharpest end towards that quarter. Lies on bed of sand.

On Clarkely Hill, hard sandstone rock forming a surface sloping down to W. striated from N.W. Several boulders of granite and gneiss on hill (*Second Report*, p. 155).

Mr William Jolly, Inspector of Schools, Inverness, sent to the Committee valuable notes regarding the distribution and parentage of Morayshire boulders, which are given in *Fifth and Sixth Reports.*

He says—"There would seem to be two varieties of Conglomerate boulders distributed through the '*Laigh of Moray.*'" *One variety* is a Conglomerate, containing "a dark purplish or liver-coloured quartzite, in pieces of considerable size." Great rocks of it occur on both banks of Loch Ness, and especially in the hill situated on the north bank called Mealfourvonie, reaching to a height of 3060 feet. This rock breaks into cubical-shaped mosses, and probably has produced the remarkable boulders in the counties of Nairn, Moray, and Banff, known as "*Culloden* or *Cumberland Stone,*" "*Tom Reoch,*" "*Clach-an-Oidhe*" or "Stone of the Virgin," 20 × 15 × 9 feet, close to Geddes Public School. "*Grey Stone*" in Cawdor woods,—"Clach-na-Calliach," or "Stone of the Witch,"—"*Clach-nan-Gillean* or *Bog's-stone,*" and various others.

The *other variety* of Conglomerate rock, found in boulders in the

same counties, "consists of more angular components, and is entirely without the liver-coloured quartzite or porphyry;" Mr Jolly says that examples of it may be seen embedded in boulder clay at Linksfield, near Elgin, and on the crest of the hill of Roseisle.

Mr Jolly adds that the boulders of this last-named variety of Conglomerate seem to have been transported at an earlier period than those of the liver-coloured variety, being generally embedded in boulder clay or drift, whilst the boulders of the liver-coloured variety lie more on the surface of the country. It is some corroboration of this view, that there are two sets of striæ on the rocks, viz., from 6° S. of West, and 15° N. of West. The Conglomerate boulders from the Loch Ness Hills may have come in the first-named direction;—the other set of boulders, across the Moray Firth, from Ross-shire (*Sixth Report*, p. 48).

FIFESHIRE.

Balmerino.—Mica schist 12 × 9 × 8 feet (now destroyed) (*First Report*, p. 32).

Crail.—Granite boulder 10 × 8 × 6 feet, "Blue Stone of Balcomie," close to sea, at East Neuk. Also trap boulder 12 × 8 × 8 feet (*First Report*, p. 32).

Dunfermline.—Whinstone boulder 7 × 15 × 6 feet "The Witch Stone."

Leslie.—Kaim of drift 100 to 300 feet wide, 220 feet high, now cut through by a rivulet (*First Report*, p. 32).

Newburgh.—Boulder of sienitic gneiss weighing 15 tons. Legend is, that it was thrown by a giant from Perthshire, viz., from North or N.W.

West Lomond.—Boulders of Red Sandstone and porphyry lying on Carboniferous Limestone rocks (*First Report*, p. 32).

Isle of May.—Small sienitic boulders on west side of island, seen by Convener. Rocks on west side, smoothed by an agency from W. ½ N. No boulders or smoothings on east side of island (*Fourth Report*, p. 22).

Bogward Den.—Three miles west of St Andrews, a Conglomerate boulder. The nearest rock of same kind is *Drum Carro Craig*, situated some miles to N.W. (*Fourth Report*, p. 22).

Kincraig.—On beach, a granite boulder with girth of 23 feet and height of 4 feet lying on trap tuff. Portions of this trap tuff found in blocks 2 miles to eastward.

Elie.—Whinstone boulder $8 \times 4 \times 2\frac{1}{2}$ feet, with striæ on its surface bearing N.W. Its longer axis N.W. (*Fourth Report*, p. 23).

East Lomond Hill, at height of 1075 feet above sea, a large number of dolerite boulders on west slope, and much rounded (*Eighth Report*, p. 28).

Auchluisky Hill, one of the Ochils, at 1025 feet above sea, a small red granite boulder lying on a slope facing W.N.W.

On ascending Benty Knowe, directly opposite to Auchluisky Hill to the west, another red granite boulder found.

The rocks of the Ochils here are trap, "a rotting clinkstone."

Bencleuch, at a height of 2200 feet has on it two boulders, one of greywacke,—a peculiar kind, marked by nodules of white quartz, which is known by Professor Heddle to occur on the north spur of Ben Lomond, at a height of from 2230 to 2240 feet above sea. The same rock also occurs about 8 miles to the east of Ben Lomond.

The other boulder is of gneiss, laminated and convoluted, like rocks occurring in the district of Loch Earn and Glen Falloch (*Eighth Report*, p. 29).

Ochils.—In Alva, Silver, and Tillicoultry Glens, there used to be many boulders of granite and mica schist; but they have been all broken up for building purposes (*Eighth Report*, p. 5).

Forfar.

Airlie.—Remarkable kaim running east from Airlie Castle 2 miles long (*First Report*, p. 32).

Barry.—Granite, sienitic, and gneiss boulders on shore, and on raised beaches 11 and 45 feet above shore (*First Report*, p. 32).

Benholm.—Huge granite boulder, now destroyed. It stood on apex of a trap knoll. In trap of this knoll are agate pebbles embedded, flattened on west side. Small hills scalloped by some agent which has passed across from west (*First Report*, p. 32).

Carmyllie.—Granite or gneiss boulder lying on a height. Differs from rocks *in situ*,—supposed to have come from hills 30 miles to north (*First Report*, p. 33).

Cortachy.—Whinstone(?) boulder, 13 × 10 × 8. Longer axis E. and W., supposed to have come from trap situated to N.W.

Mica schist boulder within Earl of Airlie's park. Parent rock supposed to be 2 or 3 miles to N.W. (*First Report*, p. 33).

Farnell.—Boulder weighing about 12 tons. Supposed to have come 30 miles from N.W.

Inverarity.—Two grey granite boulders from 2 to 5 tons.

Kirkden.—Kaims of gravel and sand 440 paces long, running E. and W.

Kirriemuir.—Granite boulders, both red and grey. Supposed to have come from Aberdeenshire.

Several kaims of granite pebbles and sand on Airlie estate, running N.W. and S.E. (*First Report*, p. 33).

Liff.—Several boulders of mica schist, called "*Gows of Gowrie.*" A Druidical circle composed of boulders (*First Report*, p. 34).

Menmuir.—Two large granite boulders, each about 35 tons, besides others of smaller size.

Montrose.—On Garnock and other hills, striæ on rocks point W. by N. obliquely across hill. On Sunnyside Hill, blocks of red shale derived from rocks *in situ* some miles to N.W. (*First Boulder Report*, p. 34).

Rescobie.—Mica slate boulder 13 × 7 × 7, near top of Pitscandly Hill, lying on drift. Rocks *in situ* are Old Red Sandstone. Late Sir Charles Lyall was of opinion it came from Creigh Hill, about 17 miles W.N.W. Valley of Strathmore lies between boulder and parent rock. There are also several hills higher than boulder between it and parent rock (*First Boulder Report*, p. 34).

St Vigeans.—Gneiss boulder now destroyed. Supposed to have come from mountains situated to N.W. If so, it must have crossed several ridges of hills and valleys. Kaim in the parish full of gneiss and granite boulders.

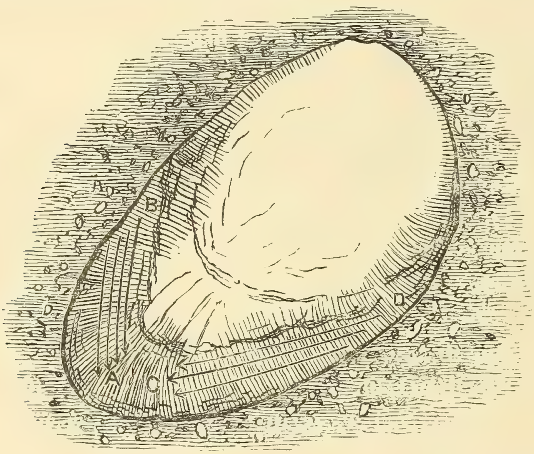
Haddingtonshire.

Prestonpans.—A large basaltic boulder on the beach, known to the fishermen by the popular name of "*Johnny Moat*," in memory of a corpulent member of their class, who had formerly lived in the village. There being no basaltic rocks towards the east, the boulder must have come from the west (*First Report*, p. 18).

Linton.—(1) On Drylaw Farm, a limestone boulder $5\frac{1}{2} \times 3\frac{1}{2} \times 3$ feet, met with in cutting a deep trench through boulder clay. The longer axis N.N.W. The N.W. end more pointed than east end, also well rounded and polished by friction. Boulder tolerably flat on upper side, but no striæ visible. On each of the two sides, meeting at N.W. end, boulder not only smoothed but striated—chiefly along side facing N.N.W.

The nearest rocks of same composition as boulder, are in Garlton Hill, about 6 miles distant, and bearing W. by N. (by compass).

If agent which smoothed and striated the sides of the boulder came, as is probable, from the westward, it seems, when it reached the boulder at A C (its west end), to have divided into two streams,—



Drylaw Boulder.

one, A B, flowing along north side E.N.E., the other, C D, along the south side S.S.E.

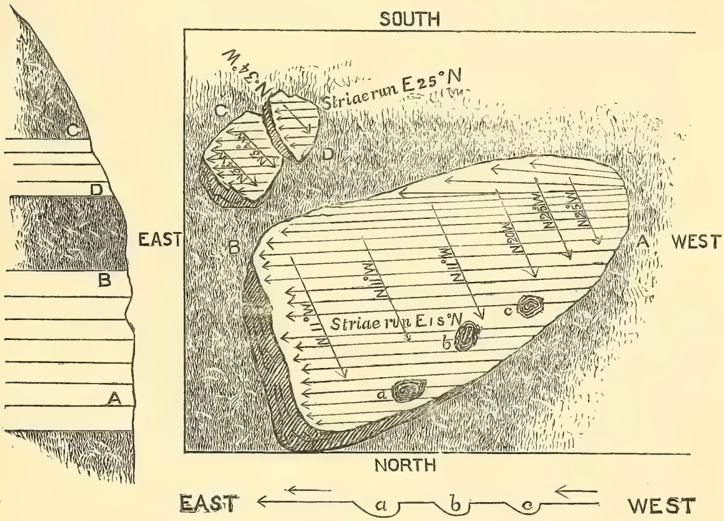
The clay in which the boulder was buried, contained blocks and pebbles, some of them, soft (such as shale, coal, &c., from the west), and others, hard (rock or greenstone, granite, &c.), quite capable of smoothing and striating the boulder, if driven and squeezed against it by some agent of sufficient weight and magnitude.

(2) In the village of Linton, several portions of porphyritic rock recently exposed, which are smoothed and striated. On one portion of rock, the surface of which is horizontal, the direction of striæ is W.N.W. and E.S.E.

On another portion, the surface of which slopes down towards north at an angle of about 35°, the direction of the striæ is due E. and W.

Each set of striæ might be produced by the same agent. If its normal direction was W.N.W., it would, on striking the rock which slopes down north, be deflected into an E. and W. direction.

(3) A still more remarkable case of the same kind occurs in a cutting of the North British Railway, about half a mile to the west of Linton station. The rock is on the south side of the line. The smoothed surface is about 18 feet high and 25 feet in



Striated Rock in Railway Cutting near Linton Station.

length. The surface there slopes down northwards at an angle of from N. 11° W. to N. 20° W. The striæ run across the rocky surface in a direction E. 15° N.—the deflection from the normal direction of the striating agent being greater here than at Linton village, on account of the larger area of the opposing surface.

It may be added that, whilst in the lower part of the rocky surface, the striæ are horizontal, near the top of the rock they rise up towards the east at an angle of 4° or 5°. If the striating agent consisted of a mass of drift, the pebbles and blocks in the lower part would move horizontally, and produce horizontal striæ. But

in the upper part of the mass, blocks and pebbles would not have the same weight above them to keep them down, and, in consequence of severe lateral pressure, they would have a tendency to rise.

North Berwick Law.—(1) An account was given by Mr David Stevenson, C.E., regarding striations on the rock of this hill. In his paper read to Edinburgh Royal Society, 1st February 1875 (vol. viii. p. 481), he states that the west side of the Law consists of exposed rock, the east side being covered by gravel, clay, and stones.

On a steeply inclined part of the hill, there is a surface of the rock, consisting of felspar porphyry, on which he found smoothings forming a sheet of about 200 feet in length, with occasional deep striæ or scorings on it. He says—"The grooving of the surface is very distinctly marked, and must have been done by the passage of some dense but yielding body, which could be moulded to the different irregularities, both vertical and horizontal, on the surface of the hill. The striæ must have been made by the passage of sharp-pointed bodies, harder than the felspar porphyry of the Law." "As viewed from a little distance, the scorings appear to be nearly parallel and horizontal; but on examining such as can be reached, I found, on using the clinometer, that this is by no means the case. On one patch of rock I found two striæ within 18 inches of each other, the upper of which had a dip of 4°, and the lower a dip of 20°, and both markings were dipping towards the *west*, being the directions from whence the movement came, as indicated by the '*tail*' on the *eastern* side of the Law. This rise in the direction of motion may have been caused by local pressure, due to the obstruction offered to the passage of the mass by the Law."

Mr Stevenson adds, that "the rock surface discovered by him had been entirely concealed by debris, till it was removed, to allow of the rock being quarried. A similar mass of debris extends along the whole northern and southern faces of the hill, and, if removed, I have no doubt similar markings would be found along both sides."

(2) The Convener of the Committee, thinking that North Berwick Law deserved a farther examination, proceeded to it, and gave the results of his examination in a paper read before the Royal Society of Edinburgh on 7th July 1879 (vol. x. p. 261).

He found that the rock surface described by Mr Stevenson is situated on the N.W. side of the Law, and that the smoothed part slopes down towards the N. and N.W., at an angle of from 65° to 70°.

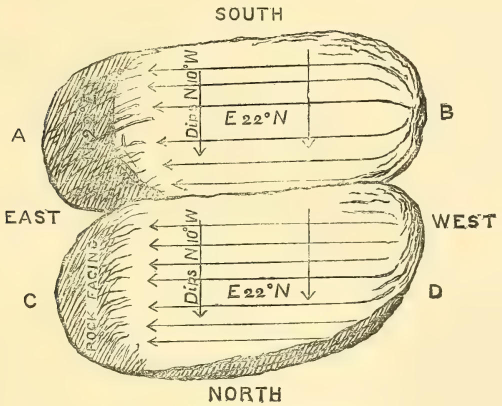
Parts of the smoothed surface face N.W., other parts face due north, and some N. by E.; but wherever the rock faced a more easterly direction, *there was no smoothing.*

The only parts of the smoothed rock surface *striated* were those fronting N.W. by N., or a few degrees on either side of that point.

Their direction is W. by S., or W.S.W.; and most of them are apparently horizontal.

Some of the ruts and striæ, especially at their west ends, are deeply incised in the rock, showing the extreme and continuous pressure which predominated there.

The particular direction in which the striating agent moved, may be inferred, by considering, that if it came in a direction *parallel*



North Berwick Law.

with the rock surface, it might grind or smooth, but would hardly produce ruts or striæ; nor would it have this effect, if it came *against* the rock surface *at right angles.* A line *parallel* with the rock surface, would be S.W., and a line *at right angles* would be about N.N.W. The intermediate point would be W.N.W.;—from which direction therefore, (the Convener inferred) the striating agent moved on and against North Berwick Law.

In the Convener's paper a diagram was given, as shown by the foregoing woodcut, of a well-marked portion of the rock, where it slopes down towards N. 10° W. The striations are very distinct, running horizontally, towards E. 22° N. But where the rock surface slopes down N. 23° E., which it does towards the east, there are no striæ, and the rock is only smoothed.

(3) On the farm of *Kingston*, 2 miles south of North Berwick, the Convener found a small boulder of red granite.

(4) A very large boulder of basalt stands on the beach, near *Tantallan Castle*, which could have come only from the westward.

Hebrides.

1. *Islay.*—(1) Near Port Askaig, on *Lossit Farm*, four or five boulders of large size. One of these 13 × 8 × 8 feet, a composite rock, extremely hard, containing crystals of quartz, augite, and hornblende; boulder resting on bed of bright yellow clay; rocks of district a slaty schist. Height above sea 300 feet.

(2) On *Arnahoo Farm*, 3 miles N. of Port Askaig and 228 feet above sea, porphyry boulder stands on summit of hill in a precarious position (pl. iii. fig. 8, in *Fourth Report*, p. 17) (*Lithograph* No. 14, Plate VIII.).

This boulder must have come from a direction N. by E., as explained in Report. Mull is in that direction. Boulder is of hard porphyry, quite different from rock of hill.

(3) On *Persibus Farm*, about 3 miles S.W of Port Askaig, four or five boulders, well rounded; all, a hard porphyritic rock, differing from any Islay rock. Their height above sea 228 feet.

Towards N. by E. an opening among hills, through which these boulders might have been carried on floating ice.

(4) On a hill, 2 miles north of *Persibus*, a boulder 18 × 12 × 1 feet, differing from adjoining rocks. Height above sea 410 feet. An igneous rock.

(5) On south of turnpike road, between *Bridgend* and *Port Helen*, a large boulder lying at north base of a hill, which probably intercepted it in its progress towards the south.

(5) On west coast, in Kilchrenan parish below old parish church, several boulders, which apparently came from N.W

2. *Colonsay.*—Notes sent to Committee by Mr Murray of 167 West George Street, Glasgow, and Mr Donald M'Neill, farmer in Colonsay, long resident in the island. The following points are taken from these notes :—

(1) By Mr Murray.—Shores on west side of island thickly strewn with boulders, many resembling yellow Mull granite.

A large boulder on west shore, called "*Fingal's Putting Stone.*"

At Kiloran, on N.W. part of island, there are many boulders.

On several ridges sloping down towards west boulders occur, some above a ton in weight (*Seventh Report*, p. 21).

On west coast there are some granite blocks of a yellowish-red colour, different from any *rocks* seen in Colonsay.

In *Oronsay Island* there are blocks of syenite, which probably may have come from Kiloran Bay in Colonsay, distant 9 miles N.N.W., also grey granite which may have come from Colonsay.

There are fragments of red granite with large crystals;—but no *rocks* of that variety, known in Oronsay or Colonsay.

On east side of Oronsay, boulder of coarse-grained granite, *pinky* in colour, which is supposed to have come from east coast of Colonsay, There are boulders of quartzite, and nodules of chocolate red sandstone—but which cannot be referred to any rocks on either Colonsay or Oronsay (*Ninth Report*, p. 17).

3. *Mull.*—On road to Torloisk from Tobermory, Professor Duns found numerous granite boulders—for most part the reddish variety—others are grey. The largest boulder seen was gneiss. A small quartzite boulder was also seen. All of them are rounded and smooth. Four boulders lie *en trainée*, the line being N. and S.

In approaching west coast of North Mull, boulders decrease in number. The contrast is most striking, as the boulders are very numerous towards east coast. "Has ice, moving from the N.W., begun to drop its entangled boulders near the west coast, and the rate of deposit increased as it passed over the tract between *Runa-Gal and Mishnish* and the S.E. of *Glen Frisa?* Be this as it may, there is no doubt as to the numerical increase of the boulders in this direction. They are all much rounded."

Ascended *Spyon More*, 2435 feet above sea-level. Found a good many boulders scattered over the hill—all, so far as could be ascertained, granites—*no granite rock occurring* in situ *in this part*

of Mull. "One of the boulders *lies on the very top of Spyon More.* Another is met with half-way down the hill. The rocks at the summit, are well glaciated; and a great heap of moraine-like debris rests on it" (*Ninth Report*, p. 27).

4. *Iona.*—On east coast of island a granite boulder 24 × 18 × 6 feet, weighing about 190 tons. Longer axis N.W. There are many boulders on E.S.E. side of island, opposite to Ross of Mull, which have led some persons to suggest that these may have been transported across the narrow arm of the sea which divides Mull from Iona. But the Duke of Argyll is quoted as thinking that the Iona granite boulders are a different variety (*First Report*, p. 27).

In Ross of Mull two varieties of granite (red and grey) extensively quarried (*Second Report*, p. 157).

About half a mile north of the large boulder above specified, there is another large red granite boulder about 12 feet square. East end rests on clay slate rocks of Iona. There is a groove (which was seen by Convener) on under surface of boulder, running N.E., indicating that it had been pushed in or from that direction (*Second Report*, p. 157).

To N.E. of Cathedral, along the shore, hundreds of granite boulders (chiefly the red variety);—several exceeding 20 tons.

The rocks of Iona are chiefly clay slate. Convener saw no other, and he was told there are no granite rocks.

At the south end of the island, many granite boulders (mostly red, but some also of grey variety) lying on high ground from 200 to 300 feet above sea. One of these seen by Convener, standing upon end, leaning against a rock on its S.W. side, as if it had come from a N.E. direction (*Lithograph* No. 15, Plate VIII.).

Most of the boulders in south end of Iona lie with longer axis N.E. and E.N.E.

Convener heard of a large boulder on west side of island in two fragments, which to his informant had suggested the idea of the boulder having been broken by falling from a height (*Second Report*, p. 155).

The highest hill on island is called "*Dun I.*" On the N.N.W. side of this hill there is a plateau at height of 230 feet above sea. On the plateau, where it joins the hill, there is a large red granite boulder, weighing about 400 tons, cubical in shape, and very

angular, $22 \times 16 \times 16$ feet, its base resting on the plateau, and its top leaning against side of hill (*Lithograph* No. 16, Plate IX.).

On ascending to summit of hill (which reaches to height of 400 feet above sea) Convener found several boulders of red granite.

Mr Allan M'Donald (schoolmaster) doubts the theory that the red granite boulders on "Dun I" Hill came from the Ross of Mull; —*first*, because the rocks at Ross of Mull do not reach to so high a level as 400 feet; *second*, because, as regards the 400 ton boulder, "Dun I" Hill is situated between it and the Ross of Mull, so that transportation from Ross is hardly conceivable. Ross of Mull bears from boulder S.S.E.

The smooth faces of the rocks in Iona, front N. by E., the rough faces front south (*Second Report*, p. 156).

In a subsequent year (1878) the Convener again visited Iona, and went to look at the large boulder on "Dun I." He then observed that the boulder was composed of coarse-grained red granite—more coarse than the boulders on east side of island previously referred to. The prevailing rocks of Iona are a fine-grained gneiss, approaching in many places to clay slate.

The boulder on "Dun I" Hill seemed to indicate that it had been brought by some agent from a north-westerly point, which agent had stranded on the hill, and stuck there, till boulder dropped from it.

Captain Stewart of Coll was with Convener when latter examined the boulder. On examining the portions broken off, as also another small boulder lying below, exactly similar in composition, Captain Stewart at once exclaimed—"This is *Coll* granite."

In reference to this suggestion, it is to some extent confirmed by the fact, that the island of Coll bears about N.N.W. from Iona, and is distant about 20 miles. But the Convener, having visited Coll a few days afterwards, did not fall in with any *granite rocks* there. They were all gneiss, with only occasional veins of granite. But he did find granite *boulders* in Coll, somewhat similar in composition to the large boulder on "Dun I" (*Fifth Report*, p. 4).

A well rounded boulder of Conglomerate was found by Convener on east coast of Iona. Heard that similar blocks occur on west shore in St Columba's Bay. There are no Conglomerate *rocks* in Iona. The nearest spot is said to be Inch Kenneth Island (on west of Mull), where, according to Macculloch, it forms cliffs about 100 feet high

(*Western Islands*, vol. i. p. 515). Inch Kenneth is about 10 miles N.E. from Iona (*Second Report*, p. 155).

5. *Staffa* was visited by Convener. He found on it, at his first visit, several small boulders of red granite. There are no rocks of granite on the island. It consists entirely of blue trap (*Second Report*, p. 157).

In a small bay on east side of island, the Convener (on his second visit) found several small boulders of red granite, gneiss, quartzite, and limestone, none of which occur in Staffa *as rocks.*

About 20 yards from this bay, Convener found an old sea-beach 36 feet above high water mark, from the gradual breaking up of which the foregoing boulders are probably derived.

Quotation given from Dr Macculloch to show how perplexed he was to account for the occurrence on Staffa of "transported stones," which, he assumes, must have been carried by natural agency from some of the neighbouring islands (*Fifth Report*, p. 11).

6. *Tiree.*—(1) *Haynish Hill*, in S.W. end of island, reaches to 600 feet above sea. It consists of gneiss, in some parts passing into granite.

The hill on its west side coincides with sea-cliffs, and has on it a number of rocky knolls. Almost every knoll has on its N.W. side (*i.e.*, facing the Atlantic) boulders more or less rounded. The following are particulars of some :—

Boulder 11 × 8 × 5 feet resting on side of knoll facing W.N.W.

Boulder 9 × 4 × 5 feet resting on side of knoll facing W. by N. at height of 360 feet above sea, which is a quarter of a mile distant, with access from the sea between S. and N.N.W. points. This boulder is a coarse granite,—the knoll is gneiss.

Boulder 8 × 7 × 5 feet resting on side of knoll facing N.W. by N. at height of 365 feet above sea. Sea half a mile distant, and access from it open at any point between S.W. and due north.

Two clusters of large boulders met with, the uppermost on the cluster so posed as to show it must have come from westward. The sea is within half a mile to westward.

On this Haynish Hill boulders more numerous on sides or slopes facing W. and N.W. than on any other. On slopes facing E. and S.E. there are also boulders, but fewer in number.

(2) Passing due north, along *Big Cornish Road*, Convener found on east side of road several rocky knolls, tops of which are from 80 to

110 feet above sea. Most of these knolls present bare rock on west sides, and have boulders on those sides. On one of the knolls a boulder $10 \times 6 \times 6$ feet, very near its top—a light coloured gneiss. Rock of knoll also gneiss, but dark coloured.

Another rocky knoll, about a mile to N.E. of last, has on it a number of large boulders called "*The Giant's Pebbles*," in reference to a legend that they were thrown by giants from Barra, an island N.W. of Tiree, and distant about 40 miles. There are here from twenty to thirty boulders of all sizes, almost all on the knoll, and none on the adjoining flat land. Suggestion offered, that knoll had intercepted the raft which carried the boulders.

(3) *Ben Gott Hill* forms a rocky ridge running N. and S. about 120 to 130 feet above sea. A very large number of boulders chiefly on its N.W. flanks. Some are on S.E. flanks, possibly pushed over ridge. On flat ground S.E. of ridge, boulders are few in number.

(4) Great beds of sand and shingle in different parts of island, showing that sea had prevailed over it at a comparatively recent period, to a height exceeding 40 feet above present sea-level.

7. *Coll.*—Visited *Bein Hoch;* hill on west side of island, reaching to 290 feet above sea. There are two boulders at top:—one near the summit which slopes down towards N.W., the other on a flat which forms summit of hill (*Lithograph* No. 17, Plate IX.).

Near foot of hill, on its N.W. side, there is a rocky plateau abutting against it, at a height of 80 feet above sea. On this low hill there is a large boulder $16 \times 20 \times 13$ feet (308 tons).

All these boulders are a coarse granite, passing sometimes into dark coloured gneiss. Rock of hill is gneiss.

The sea (viz., Atlantic) is towards west and north, distant about half a mile.

There can hardly be no doubt, that *these boulders were brought here across the sea.*

(2) At *Grassipol* an immense accumulation of boulders in a meadow, which has a range of vertical rocks on its S.E. side (*Lithograph* No. 18, Plate IX.). These boulders seem to have been intercepted in their farther progress by the rocks on S.E.. Sea is about three-quarters of a mile distant to N.W. One of the boulders is 30 feet high.

On west side of this meadow, a rocky knoll covered by boulders,

about 18 or 20 in number—the uppermost resting on the others in such a way as to show it had come from N.W. (*Lithograph* No. 19, Plate IX.).

Near this knoll, a vein of quartz, smoothed on its edges in such a way as to show smoothing from N.W.

(3) On east side of island, near Arinagour, the boulders few in number and small. Towards the N.W. part of island, when Arniboat schoolhouse is passed, boulders increase in number and size.

(4) At S.W. end of island, there are many large granite boulders near Coll House. Convener measured one and found it 35 × 15 × 8 feet (312 tons). It was on its S.E. end, leaning on or pressing against a gneiss rock. The granite boulder is of a coarse variety, the fragments composing it being of large size. This was probably the boulder which Captain Stewart was thinking of, when he compared the large Iona boulder to Coll granite.

(5) Macculloch, in his account of the Geology of Coll, refers to a "block of *augite*" which he found at a great distance from the shore, and which he thought must "be a *transported block*," as he had seen no rock of that kind in the island. He says that it probably came from Rum Island, where that rock abounds. Rum is situated N. by E. from Coll, and distant about 20 miles.

Convener omitted to inquire for this augite block.

8. *Eigg.*—Mr M'Pherson, proprietor of the island, drew out for the Committee some valuable notes.

One large boulder rests on the Scoor ridge,—a remarkable ridge of pitchstone porphyry which runs for about 2 miles across the island in an east and west direction. It reaches, at its east end, to a height of 1300 feet above the sea—at its west end, to a height of 900 to 990 feet. It rises from a plateau which is about 400 feet above sea.

Both north and south sides of the Scoor are precipitous, almost vertical, showing a cliff on the north side of 270 feet, on the south side of 400 feet.

The boulder on this ridge is near its western extremity, and on a part of the ridge which is lower than any other part, viz., 890 feet above sea. It is close to top of ridge, and on the slope facing the north.

This boulder is said to be of granite or gneiss—a rock not existing in the island.

Many other boulders of the same kind are strewed over the island.

On N.E. part of island there is a granite boulder of a larger size than any other, and is of a darker colour. It is on the side of a hill sloping down towards S.W., at about 300 feet above sea. Hill itself is about 900 feet above sea. Mr M'Pherson says that he has seen on the shores of Loch Alsh, to the east of Skye, rocks resembling this boulder.

Chips of these Eigg boulders were procured. They were submitted to Professor Geikie. Among the chips he detected one which appeared to him to have come from the Torridon group of Old Red Sandstone, viz., the coast of the mainland to the north-east of Skye.

Professor Geikie, in his account of the Geology of Eigg, adverts to the finding of "pieces of Red Sandstone of Cambrian derivation," which (he says) make it clear that the higher grounds from which they were borne could not have lain to the S. or E. but to the N.W. or N." (*Lond. Geol. Soc. Proc.*, vol. xxvii. p. 309) (*Ninth Report*, p. 22).

9. *Canna.*—Convener told by an experienced contractor for building that he had found on the islet of *Sanda* (forming the south side of Canna harbour) blocks of a red sandstone, which he made use of for the lintels and corners of a new schoolhouse. The largest was 6 × 4 × 2 feet. These sandstones differ from the rock of the island, which is a blue slaty schist, ill-adapted for building. He knew that these sandstone rocks abound in Rum Island, as he had quarried them there.

Macculloch noticed these red sandstone blocks on Canna, which he says differ from Canna *rocks*; and he states that similar sandstone rocks occur in Rum and Skye (*Western Highlands*, vol. i. p. 467).

10. *Barra.*—A very large boulder of coarse gneiss approaching to granite exists here near the base of Ben Erival, on its side sloping down to north. The hill reaches to about 600 feet above sea-level. Height of boulder 28 or 26 feet, its extreme length 37 to 38 feet, and its width about 18 feet; assuming 2 tons for one cubic yard, its approximate weight would be 890 tons (*Fifth Report*, p. 12) (*Lithograph* No. 20, Plate IX.).

Convener prevailed on tenant of the hill to dig under the boulder to discover the nature of the materials forming its site. An account

is given on p. 67 of the Report, from which it appears that the materials were gravel and earth, with sea shells. The boulder was evidently not lying on rock.

The supposition of the Convener was, that when brought to its present site it fell on what was then sea-bottom. The site of the boulder is now 230 feet above sea.

A plan is given in the Report, to assist consideration of the question, from what direction the boulder probably came to its present site ;—the result of the Convener's consideration being that it must have come either from the N.W. or the N.E., there being open sea only in these two directions.

About 100 yards to the west of the "*Big Boulder*" there is a rocky isolated knoll, about 255 feet above the sea, clustered with boulders. These are lying partly on rock, partly on shelly gravel, and chiefly on the N.W. side of the knoll. On a study of the positions of the boulders on this knoll, it appeared to Convener that the uppermost boulders to get into their positions must have come from N.W. point.

About 200 yards N.E. of "*Big Boulder*" there is a boulder lying on a smoothed rock surface, which dips due north on an angle of 20°. This boulder is 5 × 4 × 2 feet. It could not have obtained and retained its position unless by having been brought from the north.

About 300 yards to S.E. of "*Big Boulder*" there is a boulder 8 × 6 × 3 feet, at height of 228 feet above sea. The boulder at its east end presses closely on rock which has prevented it moving further in an easterly direction (*Lithograph* No. 21, Plate IX.).

On N.W. of *Ben Erival*, where its sides slope down steeply to the sea, there are numerous boulders, many of which press against the rocks of the hill in such a manner as to show that they must have come there from some point between west and north. They are at various heights from 400 to 500 feet above sea, *which is here the Atlantic.*

Ben More is a hill on Eoligarry Farm. Its west end forms a steepish sea-cliff rising to a height of 330 feet above sea. Half-way up this sea-cliff there is a boulder, 20 × 10 × 5 feet, resting on the rocky surface, which here dips W.S.W. But the rock, judging by the marks on it, has been smoothed by something passing over it

from N.W., and the boulder is *blocked at its S.E. end* by a rocky portion of the hill (as shown by *Lithograph* No. 22, Plate IX.).

At *Castle Bay* (at south end of Barra) the hills are covered with boulders, but more on their N.W. slopes than on any other.

Mr Campbell (*Paper on " Glacial Phenomena of Hebrides"*) states that he took rubbings of striæ at Castle Bay, which showed that striating agent had moved from N. by W. (magnetic).

He mentions that on the small island of *Bernera*, about 12 miles south of Barra, he got striæ at a height of 720 feet above sea, crossing the strike of the rocks from N.N.W.

On hill called *Scurrival*, whose west side rises abruptly from sea to height of 240 feet, the hard gneiss rocks show proofs of a grinding action on them from N.W. The strata are horizontal, and form blocks with their longer axis lying about N. and S. The west sides of these blocks facing sea present frequent smoothings, especially at their north ends, whilst the south ends remain rough, showing action on the blocks from N.W.

On this hill the boulders are numerous, and many of them are blocked at their S.E. ends. They are from 200 to 300 yards from the sea, and about 100 or 150 feet above sea-level. The situations and positions of these boulders combine to show that they must have come here from a north-westerly direction.

On the summit of the hill, which consists of well rounded and smoothed surfaces of gneiss, numerous boulders lie scattered, most of them on that part of the top which faces W.N.W.

11. *South Uist.*—Near south end, there is *Carshavaule Hill,* on west side of which is Loch Dunkellie. On east bank of loch, a gneiss rock well striated,—the striæ running N.W. by N. At a little distance to S.E., on south of Carshavaule Hill, a valley through which current might have passed, after striating the rock.

Loch Boisdale.—On east coast. *Kennet Hill,* situated on north side of loch, presents numerous examples on its west flanks of smoothed surfaces and of large boulders, many of them abutting on rocks at their east ends (see Diagrams in *Fifth Report*, p. 17). One of these boulders is $19 \times 13 \times 8$ feet, 146 tons (*Lithograph* No. 23, Plate IX.).

At junction of roads from Barra and Loch Boisdale, where Roman Catholic and Free Churches are situated, there is a cluster of

boulders. One 16 × 6 × 5 feet, leaning on the others, must have come from N.W. to attain its position.

On hill to east of *Askernish*, and on *Mingary Hill*, there are many large boulders, chiefly on west flanks, as also striated rocks, well deserving of study (*Lithograph* No. 24, Plate IX.).

About 3 miles to north of Askernish there is a block of granite perched on the pointed summit of a rocky hill. The boulder is 14 × 12 × 8 feet (about 100 tons) (*Lithograph* No. 25, Plate IX.). There is no way in which it could have attained its position except by floating ice.

At *Jocdar*, 1½ miles south of ferry between Uist and Benbecula, there are smoothed rocks "*literally covered* by parallel striæ, ruts, and grooves," the direction of which is N.W. by W. The smoothed surface of the rocks here slopes down to westward, at an angle of about 10° or 12°. Some of the ruts are 4 or 5 feet long. One at its N.W. end measures 8 inches across and 2 inches in depth; another 12 inches across and 1½ inch deep. Towards the S.E. they lessen in width and depth. There can be no doubt that the striating agent here came from N.W. The height of this place is about 25 feet above the sea—the Atlantic—and ¼ of a mile distant.

There is a similar good example of striated rocks about half a mile to the west of the above mentioned ferry (*Lithograph* No. 26, Plate X.).

On road between *Grogary* (mansion-house of Lady Gordon Cathcart) and *Loch Skiport* (on east coast) there are many striking examples of striated rocks and boulders.

Loch Eport is a remarkably narrow area of the sea on the east coast, which runs more than half-way across North Uist. From deck of steamboat Convener saw, on both sides of Loch, many boulders, resting chiefly on rocky knolls, and many rocks with faces smoothed on west sides.

North Uist.—Loch Maddy, a sea-loch on east coast. An hour's walk for about a mile from the shore, showed Convener that rocks here have their smoothest sides facing N.W. (*Fifth Report*, p. 22).

Professor Heddle, in a subsequent year, visited *Loch Maddy*, and reported that rocks there generally showed smoothings by some agent passing over them from the westward.

He refers also to two islets of trap rock called Maddy More and Maddy Beg, which are (as he says) "porpoise-nosed to the *west*, and

cliffs to the *east*," as indicating probably the direction of the agent which flowed over them.

Professor Heddle on this occasion, at Loch Maddy, met a gentleman, a member of the Glasgow Geological Society, who had just returned from Newton on the coast of North Uist. He described to the Professor a boulder he had seen there, $13 \times 5 \times 4$ feet, and another $9 \times 5 \times 5$ feet. The former lay with its longer axis N.N.W. He stated also that the rocks on the west shore were generally glaciated, and from points between N.W. and S.W. (*Sixth Report*, p. 34).

On *Canneum*, a rocky islet north of Loch Maddy, there are two boulders of Laurentian gneiss, weighing, the one about 15, the other about 50, tons. From the corresponding slopes of the two ends which face each other, it has been inferred that they were originally one boulder, though now about 100 feet apart from one another, and with a projecting rocky knoll between them. The reporter, Alex. Carmichael, suggested that the boulder may have fallen from a height on this rock, and been broken into two fragments (*First Report*, p. 35).

Harris.—(1) At *Rodil* (south end of Harris), rocks on Strondavelhill smooth on west faces, rough on east faces.

(2) At *Borve*, on west coast, a remarkable assemblage of boulders on hill about 800 feet high, sloping down to W. by N., close to shore of the Atlantic (*Lithograph* No. 27, Plate IX.). The boulders lie on and against benches of gneiss rocks, these rocks also being smoothed and ground down from westward. These boulders lie in such a way as to show they have come from westward (*Fifth Report*, p. 23).

(3) Similar appearances in *Loch Castle Bay* and *Valley*.

(4) About $1\frac{1}{2}$ mile south of Tarbert, several large boulders, which probably reached their positions by coming through depressions existing in the range of hills to N.W.

(5) On hills north of Tarbert, up to height of 800 feet above sea-level, Convener saw many evidences of a N.W. current loaded with ice, which has brought boulders and smoothed the rocks (*Fifth Report*, p. 26, plate viii. fig. 28).

Professor Heddle separately visited Tarbert, and specifies certain hornblendic boulders, which he traced to a rock identical in character a few hundred yards to westward (*Sixth Report*, p. 35).

(6) At *Fincastle*, on shore west of Loch Tarbert, Convener found boulder so situated as to indicate transport from N.W.

(7) *Scalpa Island.*—Three granite boulders found by Professor Heddle (*Lithograph* No. 28, Plate IX.), one of them "*butted up*" against a knoll of gneiss rock (see plate xviii. fig. 6, in *Sixth Report*, and p. 35).

On faces of hill on Harris shore, opposite Scalpa, a great bed of granite, from which Scalpa boulders probably came.

(8) *Shiant Islands.*—On western shores Professor Heddle found several blocks of rocks foreign to the islands, and occurring *in situ* in the Long Island to the west. Some Conglomerate boulders he considered had come from Stornoway, 30 miles to north, the nearest place for Conglomerate rocks (*Sixth Report*, p. 36).

Boulders of trap on eastern shores of the islands supposed to have been pushed from rocks on west side of the islands (*Transactions of Norfolk and Norwich Naturalists' Society*, vol. iii., 27th Jan. 1880).

12. *Lewis.*—Professor Heddle examined the district between Tarbert in Harris and Stornoway on foot, a distance of 28 miles. He was struck with the general flatness of the district, especially in its northern part, considering that the rocks there come generally to the surface, and are on edge. They suggested the idea of some great abrading agent which had passed over the district (*Eighth Report*, p. 29).

(1) Near *Ardvourlie*, on Loch Seaforth, a *trainée* of boulders, forming a line E. by N. and W. by S., apparently traceable to gap in chain of hills to S.W.

Clusters of boulders seen there, so piled on one another as to show that the topmost had come from westward.

(2) At and near *Soval*, 12 miles south of Stornoway, rocks forming cliffs, smooth on sides facing west, rough on sides facing east.

On one of these cliffs facing the west there is a boulder on edge of rocky cliff, which there forms a surface sloping down towards W.N.W. at an angle of from 20° to 30°. Longer axis of boulder W.N.W. Seemed to Convener clearly to have come from westward (*Sketch in Fifth Report*, plate viii. fig. 29).

(3) *Lochs Ourn and Shiel*, on *east* coast. Boulders seen by Convener on hills adjoining, positions of which all indicated transport from west.

(4) *Uig*, on *west* coast. Rocks near road at two spots, smoothed

and striated from W.N.W. Ruts deeper at west ends than at east ends (*Fifth Report*, p. 28).

(5) *Miavig*, an arm of sea branching up from Loch Roag on *west* coast. On top of a hill called *Dramainan Voltas*, 270 feet above sea, there is an immense assemblage of boulders, chiefly on north and west slopes (*Lithograph* No. 29, Plate X.) (*Fifth Report*, p. 29).

(6) *Garry-na-hine* to *Carlowrie*. Rocks along and near road, show smooth faces towards west. At low levels they vary in their aspects, as W.;—W. by S.;—and even W.S.W. But at higher levels, viz., above 300 feet, the smoothed faces are pretty uniformly towards W.N.W. (*Fifth Report*, p. 30).

The explanation of this seemed to be that the rocks at high levels were exposed to a normal current from N.W., whilst rocks at low levels were exposed to diverging and eddying currents.

Convener examined particularly striated rocks described by Dr James Geikie (*Lond. Geol. Journal* for 1873, p. 537), who expressed an opinion that the striæ had been formed by a glacier which moved across the slope of the rocks from the S.E. The Convener, after twice examining these rocks, was of opinion that the striæ had been formed by some agent passing from the N.W., inasmuch as individual striæ were most deeply cut at their N.W. ends (see sketches in *Fifth Report*, p. 30, and plate viii. fig. 32).

Boulders seen leaning against rocks on their east sides, as if thereby stopped in their progress eastwards.

(7) *Beinn-a-Bhune*, a hill about 400 feet above sea, mentioned by Dr Geikie. Rocks seen by Convener smoothed, and boulders so situated as to show probable movement from W.N.W.

(8) *Barvas Hills*, 800 to 900 feet high, 5 miles north of Stornoway, examined by Convener, who found on them smoothed rock, and boulders indicating movement from N. and N.W.

(9) In *district* between *Barvas Hills and sea-coast* to north there are long lines of escars, composed chiefly of coarse gravel, with boulders lying occasionally on their ridges; these boulders in many places piled on one another, and in such a way as to show transport from N.W.

Several of these escars run for miles continuously, and reach to the north coast, following a direction generally N.W., with occasional deflections.

When viewed from top of Barvas Hills they form a striking feature, as the bright green of the grass covering them contrasts with the dark brown or black colour of the widespread muirs which they traverse.

These escars reach to a height of from 30 to 50 feet above the adjoining flat ground. At one place (about 2 miles north of Barvas Hills) an escar expands and divides into a series of knolls, on which many boulders now rest. The highest knolls have on them the greatest number of boulders. At two places the boulders form groups, piled on one another. They had formed (as was mentioned by a shepherd) hiding places in times of trouble. Most of the boulders on these escars show transport from N.W., but some indicate a transport from W.S.W.; one from N.N.E.

In this part of the island there are numerous lakelets, whose longer axis is generally parallel with the lines of escar,—a fact all the more remarkable, as the outcrops of the gneiss rocks generally form lines in the direction of N.E. and S.W. and dipping S.E.

Dr Geikie was much struck with this fact, and expressed an opinion that the formation of the escars and of these lakelets must be due to one and the same agency, viz., a glacier or ice-sheet, which came across the "*Minch*" from Ross-shire.

(10) Along coast from *Barvas*, *eastward*, boulders of granite, differing from any rocks near them, and alleged by a local mason seen by Convener to be same as rocks 7 or 8 miles to westward.

A great monolith here, 18 feet 9 inches high and with a girth of 16 feet, called "*Clachan Treudach*" or "*Gathering Stone.*"

(11) *Dalbeag Hills*, about 9 miles west of Barvas. Smoothed rocks and boulders indicating movement from westward.

(12) At *Tolsta* (12 miles N.E. of Stornoway) a boulder 18 × 5 × 4 feet, and 358 feet above sea, called the "Rocking Stone." Rocked when Convener lifted it, or when he rested his weight on it, at either end of its longer axis. Its central part rests on bare smooth gneiss rock. Its longer axis points N.N.W. It is well surrounded by high hills;—but towards N.W. there is an opening in the range of hills through which boulder might have come (*Fifth Report*, p. 31).

(13) *Eye Peninsula* to east of Stornoway, where rocks are Old Red Sandstone. Boulders of gneiss occur there, which almost certainly must have come from Barvas Hills, situated about 7 miles to N.W.

(14) On *Eye Peninsula* a brickwork of boulder clay, in which, at a height of about 200 feet above sea, fragments of marine shells seen by Convener.

Dr Geikie mentions those, and states that similar shells were found by him in a deposit stretching across the north part of the Lewis, from shore to shore (*Fifth Report*, p. 36).

(15) With reference to the above-mentioned group of islands, sometimes called the Long Island, remarks of a general character may not be inappropriate.

Mr J. F. Campbell (formerly of Islay), author of *Frost and Fire*, wrote as follows to the Convener :—

"In the Long Island, from Barra Head to the Butt of Lewis, the whole country is glaciated, with boulders everywhere perched on the hills. Wherever the surface is newly exposed, the striations and smoothings are so perfect that the marks can be copied as '*Brasses*' are copied."

In a letter from the same gentleman to Mr Alex. Carmichael of the Inland Revenue, a native of the Hebrides, the former remarks :—"Glacial striæ occur upon fixed rocks in Tiree, Mingley, Barra, South and North Uist, and correspond with a direction from N.W. or thereabouts. The hills are ice-worn to the very tops. Transported blocks are scattered over all these islands."

13. *Skye.*—The Convener regrets that the Committee received no report from this island; nor had he an opportunity of visiting it himself, except at one spot, viz., *Loch Scavaig*, on the west coast, where the steamboat stops for an hour to allow passengers to see *Coriusk.* The Convener then saw and examined a large boulder (*Lithograph* No. 30, Plate X.). Its position, on a rock between the sea and the adjoining lake, is described on page 66, *Sixth Report.* The rock on which it stands slopes steeply towards W. by N., and it is in so precarious a position that it must have been very gently let down by the agent, whatever it was, which transported it.

Professor Heddle reported that in the year 1879 he walked along N.E. part of Skye from Aird Point to Portree, and partially among the hills, but saw no boulders.

He visited Stainchol Island, situated off the east coast, and found Cambrian Conglomerate blocks, similar to what he had seen on the Shiant Islands, and similar also to the rocks existing in the Lewis,

near Stornoway. On Stainchol shore the Professor found dolerite boulder containing Labradorite. He states that the parent rock is situated about fifty yards to N.N.W. (*Sixth Report*, p. 38).

Judging from what is casually said by Dr Macculloch and Principal James Forbes, regarding boulders in Skye, they must be numerous and interesting. Thus Forbes refers to boulders "*poised upon others, or fantastically balanced on the tops of elliptical domes of rocks;*" and Macculloch says that the summits (on which some of the boulders stand) are not only bare, but often very narrow, while their declivities are steep, and sometimes perpendicular. Macculloch confesses his inability to explain these phenomena.

Inverness-shire.

Loch Nevis, on west coast. Several large boulders of coarse-grained granite seen near Inverie House, lying on slate rocks.

On road towards Gussern, several boulders of interest pointed out to Convener by late Mr James Baird, the proprietor.

At height of 360 feet above sea, and near sea-shore, rocks smoothed and striated from N.W. by W.

Two large boulders lie on side of a hill, which slopes down to the W.N.W. One of these, of elongated shape, has its longer axis N.W. and S.E.

A large boulder, consisting of two fragments, pointed out by Mr Baird, in consequence of his believing that the boulder had been broken by falling from a height, and striking on the bare rock, where these fragments now lie. The two fragments are four or five feet apart. Whilst the opposing surfaces correspond in shape, they are so weathered, as to show that the fracture was not of recent date.

At summit level between Inverie and Gussern, there is a horizontal terrace, facing the sea, and at from 400 to 500 feet above sea, with a number of boulders on it.

At Invergussern, lower part of valley blocked by a huge gravel ridge, now cut through by river, quite in the position of a terminal moraine. But, being composed of nearly horizontal beds of gravel and sand, from 40 to 50 feet deep, more probable that it is a sea deposit, and that it for some time confined a lake; for on the sides of valley horizontal water-lines occur (*Second Report*, p. 164).

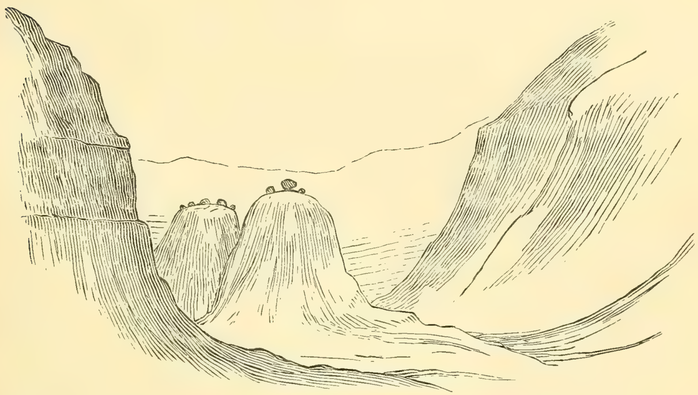
2. *Loch Corry,* near Morvern, has its rocky shores well glaciated. A large knoll of red granite, at mouth of loch, has had its W.N.W. sides rounded, and partly striated up to 150 feet. The S.E. side of knoll rough and craggy (*Eighth Report,* p. 29).

On north shore there is an angular block $27 \times 27 \times 11$ feet, apparently moved 28 yards from a rocky cliff situated to N.W., of which it had been part. The hills on the Glen Sanda property, reaching to a height of 1800 feet and more, are glaciated to their very tops.

3. On *Loch Shiel,* several similar cases of large blocks (from 1 to 10 tons weight) apparently forced from rocky cliffs and carried eastwards.

White granite vein or dyke met with near top of hill, 2718 feet above sea, from outcrop of which, blocks detached, and carried eastward nearly one-third of a mile.

4. In *Glen Oban,* remarkable examples of rounded rock-surfaces, some more than 100 feet high; also of "*perched boulders,*" on isolated rocky knolls, each from 300 to 400 feet high, and inaccessible, as shown in woodcut annexed.



Glen Oban, showing Perched Boulders.

5. *Mid Lochaber.*—Memoir by Rev. Professor Duns, on Surface-Geology of, and particularly on the boulders found to N. and W. of Ben Nevis. The Professor says—" Granite boulders are lying on the mica schist rocks, where the side of the mountain slopes down so steeply as to make it a puzzle to understand how they can remain in position."

The author expresses belief that the phenomena may find explanation in the recognition of two movements,—one outward from Ben Nevis as a centre, the other a force travelling from the W.N.W. or N.N.W. (*Eighth Report*, p. 21).

Notes on boulders, situated to the *west of Fort-William*, by Mr Colin Livingston, teacher of public school, Fort-William.

The author enumerates boulders and striated rocks on west side of Ben Nevis, and expresses a confident opinion that two glaciers existed, the one descending Glen Nevis, the other Glen Spean and Glen More.

He refers to immense mounds and ridges of detrital matter, (having an imperfect stratification) towards Inverlochy and Torlundy, —such as might have been produced, if it fell from some height (*Eighth Report*, pp. 23, 27).

6. Since the time when Mr Livingstone's Notes (given in the Eighth Report) were framed, he has made a further inspection of the hills to the W. and S.W. of Ben Nevis, and has communicated to Convener the following additional facts:—

Stob Ban, reaching a height of 3274 feet above sea, is situated west of Glen Nevis. It is composed of quartzite, which accounts for its Gaelic name of *White Pin*. Boulders of this rock are found to the eastward, on various parts of the west slopes of Ben Nevis.

Another hill of interest is "*Mulloch-Nan-Coirean*," 3077 feet, having a rounded top of red granite. On its top there is a slab of mica slate. How it came there, Mr Livingstone says is a mystery. He admits that mica slate rock exists in large quantities towards *Sghor Challum*, a hill 1823 feet, situated to the *west*. But he sees the difficulty of conceiving that any *glacier* could have brought it.

On the same hill there are boulders of micaceous gneiss and quartz. The quartz boulders, he says, may have come from *Stob Ban*; the birthplace of the gneiss boulders is (he says) uncertain.

7. Notes on *Ben Nevis* and *Craig Dhu*, by Professor Heddle of St Andrews, were sent to Committee. He expresses an opinion that a glacier swept down Glen Nevis, even overtopping a hill of 3077 feet. He also suggested the probable existence of another vast glacier cradled in the gorges between Aonach Beg and Aonach Mor.

8. *Ben Nevis.*—Convener ascended to top, by a path leading up the N.W. side of hill. Enormous boulders of grey granite lie on N.W. slopes. A few on each side of path were measured, and gave

the following results:—16 × 10 × 10 feet (118 tons) (partially sunk in gravel); 15 × 7 × 5 feet (lying on bare rock); 13 × 7 × 4 feet; one nearly cubical, the sides being each about 4 feet square. The first three have longer axis N.W. They are from 900 to 1200 feet above sea. But there are some, up to 2000 feet above sea. Mr Doig, builder, Fort-William, who accompanied Convener, mentioned that there had been one boulder at the foot of mountain, on its N.W. side, so large as to afford materials for building the entire front wall of the Town Hospital of Fort-William.

Mr Doig stated that he considered that the boulders on west flank of the mountain were generally different from Ben Nevis rocks (*Fifth Report*, p. 65).

9. On *Treshlik Hill*, 1566 above sea, on north side of Linnhe Loch (opposite to Fort-William), Convener, under guidance of Mr Livingstone, inspected a coarse-grained granite block, 8 feet high, 52 feet below summit, on west slope of hill. This hill forms a ridge about half a mile long, running W.S.W. Rocks *in situ* are clay slate. Boulder must have been transported from some westerly point, and put down very gently, as slope exceedingly steep where boulder rests (*Lithograph* No. 31, Plate X.) (*Second Report*, p. 161).

Rocks on north and west sides of hill near top are well smoothed; rocks on S. E. side of hill are rough. The smoothed rocks are chiefly on a space along north side of hill, from 30 to 60 feet below summit. Many coarse-grained granite blocks, and water-worn pebbles, lie along north face of hill near the top.

10. *Boleskien, Abertarff, and Dores.*—Well rounded granite boulders of red and grey varieties occur over district of Stratherrick. One above ground measured 20 × 10 × 7 feet, and there seemed to be as much below. Its longer axis N. and S. Another at Fall of Foyers measured (above ground) 12 × 6 × 6 feet.

Several are *poised on tops of isolated hills.* Highest hills in this district about 2900 feet above sea. Boulders are chiefly above the level of 2350 feet. Below this level they are generally of a smaller size. Reported by Captain White, R.E. (*Second Report*, p. 137).

11. *Lochaber.*—In this district one of the most interesting hills is *Glen Dhu* 2200 feet, between Glen Roy and Glen Spean. Professor Heddle, having visited it, expressed an opinion that the large

boulders on and near the top had come from a S.S.E. direction (*Eighth Report*, p. 37).

As other geologists have visited this hill, and recorded views which contain further information, it is right to refer to them. Thus Mr Jamieson of Ellon mentions having seen several large boulders of syenitic granite on or near the top of *Craig Dhu*, a gneiss hill, at a height of 2100 feet above sea. He says—"What is remarkable is, that the largest and most angular are more numerous high up on the very brow of the hill than further down. Thus" (he says), "one 12 × 9 × 6 feet lay only 130 feet below the summit; another was a magnificent block, 15 × 10 × 6 feet" (*L. G. S. J.*, vol. xvii. p. 175).

The late Professor Nicol of Aberdeen, well known as a geologist, refers to the *Craig Dhu* boulders in these terms:—

"I found huge blocks of black granite and smaller masses of red porphyry within a few yards of the *summit* of *Craig Dhu*, a conical mountain of mica slate. One block must weigh 40 tons. They are evidently ice-borne, probably floated from the N.W." (*Lond. Geol. Soc. Proc.*, August 1869, p. 283).

The Convener visited *Craig Dhu*, and noted the following points:—(1) The boulders on the hill, in so far as not of a round shape, have their longer axis E. and W. A little above 1391 feet level, found boulder on bare rock, which here forms a flat surface, glaciated like the rest from W. by N. The boulder must have come after glaciation of rocks. Looking towards west, saw a line in that direction clearing all the hills, showing an opening for a movement from west towards and upon *Craig Dhu*. Masses of white quartz rock were found glaciated from west. A boulder near top of the hill, with longer axis W. by S. (*Edin. Roy. Soc. Trans.*, vol. xxvii. p. 641).

Mr Jamieson refers to a granite boulder on the *top* of *Bohuntine*, a hill 2000 feet high, not far from *Craig Dhu* (*Eighth Report*, p. 639.)

Mr Jamieson, in describing smoothings and scorings of the rocks at *Loch Treig*, up to 1280 feet, states that he found "*perched boulders*" and rounded surfaces of rock much higher, and *even up to the top* (about 3155 feet above the sea). The gneiss, though it runs in nearly vertical stratifications, is neverthe-

less so free from any loose fragments on its surface, and the ends of the strata are often so rounded in outline as "to raise a suspicion that some *denuding agent had flowed over it*, at a period geologically recent" (*Lond. Geol. Soc. Proc.*, vol. xviii. p. 172).

The following cases of boulders were reported by the Convener :—

On the summit of the hills, at the head of *Glen Roy* (1320 feet above the sea), there are enormous granite boulders. "Some rest on bare rock, but traces of clay and gravel in their vicinity suggest that they may originally have been embedded in drift, which has been since mostly washed away from under and about them" (*Edin. Roy. Soc. Trans.*, vol. xxvii. p. 639).

The late Charles Darwin, who visited Lochaber, and wrote an instructive memoir on the "Parallel Roads" question, refers to the *Ben Erin* hills,—their height reaching to 1600 feet above the sea. He says that "on the mountains between Glen Roy and Glen Glouy, on a hillock N.N.W. of the summit of Ben Erin, I found several masses of *granite*, one of which was 4 × 3 × 2 feet, resting on the surface of the *gneiss*. This hillock seemed to be entirely composed of the latter rock, and it was separated from all other hills by a valley. On the flanks of Ben Erin, at about the same level, there were several boulders of granite."—"With respect to these Ben Erin boulders, they are completely cut off from every granite district by valleys, the *highest point of which* is 920 feet *below a boulder*, the altitude of which I measured; that is, it would be impossible to walk from granite *in situ*, to these boulders, without ascending at least that number of feet" (Darwin, "On the Parallel Roads of Glen Roy," *Phil. Trans. of Roy. Soc. of London*, for 1839, page 69).

Sir John Ramsden of Ardverikie (on Loch Laggan) informed Convener that on *the top of two contiguous hills*, forming part of his estate, east of Loch Laggan (one of these hills exceeding 3000 feet in height), there are large granite boulders.

Sir John Ramsden guided the Convener to the *Wester Beinin Hill* (situated on the west side of Loch Laggan) to see several *grey* granite boulders. The rocks of the hill are *red* granite. One of the boulders is on a shelf about 1516 feet above the sea, on the side of a hill sloping down to W.S.W.

Facts bearing on the *direction* of boulder transport in Lochaber have been noticed by several geologists. Thus, Mr Jamieson mentions that on the hilly ridge between Glen Spean and Glen

Gluoy the direction of the striæ at a height of 800 or 900 feet above the sea is from W. 20° N. to W. 40° N.; and as "the western sides of the rocks were most worn, the action had come from that side" (*Lond. Geol. Soc. Journ.*, 21st January 1863, p. 246).

In Glen Roy (at about 1200 feet above the sea) he found, much to his surprise, that "ice had come from the S.W. *up the glen*, and had gone out in a wide stream, towards the wide valley of the Spey," viz., eastward.

11. *Black Mount district, near Rannoch.*—Boulders of a peculiar white granite, found by Professor Heddle, forming a *trainée.* He investigated from what hills they came, and traced them to Albannach Hill, reaching to a height of 3425 feet above the sea, and situated about 10 miles N.W. from Loch Tulla.

Reference is made by the Professor to an enormous boulder weighing about 1900 tons, in a narrow part of a valley at Loch Dochart, where traces were seen of some very "powerful agent" which had passed through the valley eastward.

12. In the *Fourth Boulder Report* (p. 14) an account is given of the *Fassnacloich* boulders, a species of black granite. Specimens were sent to Mr Judd of London, on account of his personal knowledge of rocks in the West Highlands. His opinion was that the rock of the boulder was identical with rocks in Mull and Ardnamurchan, from which district, therefore, he supposed the boulders may probably have been transported.

On the shore of the Linnhe Loch, *at Appin*, there are two huge well-rounded boulders of the same kind of granite. Their position favours Mr Judd's suggestion, that all these boulders had been transported from the westward.

The granite boulders on the top of *Craig Dhu*, already mentioned in Lochaber, are of a dark colour. Is it possible that the mountains of Mull and Ardnamurchan could have supplied all these boulders when the sea stood 2000 feet or more above its present level? (*Fourth Report*, p. 45).

12½. *Ardgour district, on north side of Linnhe Loch.*—Professor Heddle of St Andrews, in *Seventh Report*, p. 36, states that on *Stob Choire a Chearchaill* he found a *trainée* of boulders lying along the ridge for nearly a mile, at heights varying from 2400 to 1800 feet above the sea. The direction of the *trainée* was N.N.W. Most of these boulders consisted of syenite, with red felspar crystals

and green hornblende. Thinking that these boulders might also be found on the south side of the Linnhe Loch, he crossed, and on two hills there, viz., *Bein Bhan*, at a height of 1500 feet, and on *Beinn na Gucaig*, at a height of 2017 feet, he found boulders of the same syenite as he had found on the north side of the loch.

In the *Eighth Report* (p. 33) Professor Heddle mentions his discovery of more boulders of the same peculiar syenite, as seen by him on hills nearer Ben Nevis and on Ben Nevis itself, at an altitude of 2200 feet. This discovery led him to change his opinion as to the direction of the transport of these boulders.

13. *Loch Creran.*—The boulders there were examined by Professor Heddle. He was much puzzled to explain from what district they came. There were striæ on the rocks of the hills adjoining, at heights exceeding 2000 feet above the sea. He was inclined to think that the boulders had crossed the Linnhe Loch from Loch Sunart and Glen Tarbert.

On some of the hills of this district boulders were discovered at heights exceeding 2000 feet, which Professor Heddle was satisfied must have crossed valleys to reach their positions, and by means of floating ice (*Sixth Report*, p. 43).

14. *Glencoe District.*—On the western slopes of a hill, in the higher part of Glencoe, near Loch Tulla, boulders of a peculiar white granite were found by Professor Heddle. They were different from the adjoining rocks. He already knew that the rocks in the hills to the eastward were also different; so, in expectation of finding the parent rocks, a search towards the west was commenced. On reaching the *Aonach-Eagach* range of hills the same kind of boulders were seen, fewer in number, but larger in size. They were lying chiefly on the eastern side of the narrow ridge leading up to the summit of the nameless peak marked 2938 feet on the Ordnance map. On the next rounded haunch (2880 feet) they were not seen, but they reappeared on the ridge as it ascended to the eastern peak of *Meal Dearg* (3090 feet), and almost up to the summit of the western peak (3118 feet). "Their position," adds Professor Heddle, was most peculiar. They lay on a ridge *not many times wider than their own bulk*, and only on the eastern slopes of that ridge; while on the lower hills, where they were first seen, the same boulder lay on the west slopes" (*Sixth Report*, p. 44). "It is a fact of considerable importance, bearing on any theory of transport, that these

boulders on *Aonach-Eagach occupy positions much higher in level than any of the hills in a very wide extent of country*, so that it is difficult, if not impossible, to adopt for them the explanation of any local glacier" (*Sixth Report*, p. 46).

In the following year, Professor Heddle returned to the Rannoch district, to search for any farther traces of this stream of white granite boulders. To the S.E. of Loch Rannoch he found two hills, *Gea Charn* and *Creag Mhor* (2595 and 2250 feet), forming a sort of ridge running nearly N. and S., and so situated as to cross what might have been the line of stream. Two boulders found, each weighing about 7 tons, very similar in colour and composition to Loch Tulla boulders. He next proceeded to Schehallion, situated about 3 miles farther east, and found on its western slope, about 140 feet below the summit, *i.e.*, 3407 feet above the sea, a boulder of the Loch Tulla group, about three-quarters of a ton in weight.

Reference is made to other geologists who had previously found boulders on Schehallion, near its top—one being Robert Chambers, who concluded from the striations on the rocks of Schehallion, that the stream which brought the boulders had flowed from W. 30° N. (*Seventh Boulder Report*, p. 34).

Convener passed through *Glencoe Valley* thrice, the last time on foot, beginning near the upper end. He was impressed with the belief from what he saw, that *ice had passed down* the glen, smoothing the rocks along bottom, and so far up each of the sides,—and carrying blocks of these rocks for some distance *down* the valley. On the other hand, it appeared to him that blocks of rocks foreign to the valley had *come up* the valley at a subsequent period,—brought therefore, by the action of floating ice. One of these, a huge mass of Conglomerate, was resting on a terrace of *gravel;* and above the gravel there were, on the hillsides adjoining, "extensive beds of *sand*," reaching to heights exceeding 2000 feet above the sea. Besides this Conglomerate boulder, there were granite boulders in such positions as to show that *they* also had *come up the glen.* The Convener concluded that the glen had first been occupied by a glacier; and that at a later period the land sank to more than 2000 feet below its present level, which would allow floating ice to pass over the Glencoe Hills, and to deposit on them some of the boulders they might be carrying (*Fifth Report*, pp. 52, 53) (*Lithograph* No. 33, Plate X.).

15. *Kilmallie.*—One boulder, 12 × 10 feet, fully 2000 feet above

sea, on *summit* of a hill. Another, larger, between Loch Shiel and Loch Askaig (*First Report*, p. 38).

16. *Fort Augustus.*—About 2 miles to S.W. of the town, on Corryarrick road, a boulder of grey gneiss, on a steep bank of gravel at base of a buff-coloured felspathic rock. As the hill-slope faces N.W., boulder seemed to have come from that quarter. It happens to be exactly at same height above Loch Ness (207 feet) as boulder seen to the east of Urquhart (*Fifth Report*, p. 64).

17. *Strathglass and Glen Urquhart* (north of Loch Ness).*—(1) On hill above *Affric Hotel*, on east side of river Cannich, at height of about 720 feet above sea, rock planed and striated, the striæ running N. by W. coinciding with direction of valley.

At height of 970 feet above sea, a granite boulder lying on upturned edges of gneiss rock—its position indicating that it had come from W. by N. (*Fifth Report*, p. 63).

At summit of hill, about 1170 feet above sea, numerous boulders found, chiefly on slopes facing N.W.

(2) On public road to Urquhart, a few miles from Affric Hotel, rocks on south side of road ground down and striated, in a line about E. and W., *i.e.*, parallel with axis of main valley.

At top of hill, about 660 feet above sea, several boulders found, resting on a bed of sandy clay, and on a slope of hill facing W. by S. The west sides of boulders chiefly rounded, as if worn by friction of bodies passing over them from west.

All the rocks exposed show smoothings on sides facing west, as far up as hill reaches, viz., 927 feet above sea.

(3) Whole of Glen Urquhart indicates, by quantity of gravel and sand on both sides, that it has formerly been choked by drift, which cut through and scoured out by the river.

(4) On north bank of Loch Ness, half a mile east of Urquhart, many conglomerate boulders lie on hill sloping towards Loch Ness, from 200 feet up to 800 feet above Loch Ness. Rocks of hill here are gneiss; Mealfourvonie hill, situated some miles to west, consists of Conglomerate rock.

* Convener made this excursion accompanied by Mr Jolly (Inverness), to ascend *Maum Saul*, a mountain reaching a height of 3880 above sea, in order to investigate the truth of a report by Ordnance surveyors, that on the west side of this mountain, at a height of 3800 feet, horizontal beds of sand and gravel had been seen by them. After the foot of the mountain was reached, bad weather prevented the ascent.

At height of 450 feet above loch, deep beds of a fine sandy clay occur.

One of the boulders is at a height of 340 feet above loch, which corresponds with a horizontal terrace on south side of loch.

18. *Glen Morriston and Glendoe, on north side of Loch Ness.*—(1) In *Eighth Report* (p. 15) Professor Heddle describes several boulders on the hills at the head of Glen Morriston, near Clunie Inn, at great heights, and some on very steep slopes, apparently transported from westward.

(2) The Convener (*Fourth Report*, p. 23) describes a visit to Glendoe, at head of Glen Morriston, where he found several boulders of large size, at heights of from 919 feet to 1205 feet above the sea. These boulders rest on gravel and sand, and in height correspond occasionally with horizontal terraces occurring on opposite side of the valley where they occur.

In a higher part of valley, viz., about 1190 feet above sea, deep beds of sand and gravel found. Terrace seen by Ordnance surveyors at height of 1280 feet, at top of glen.

The Convener was told of a still larger boulder, about 16 feet high, at Clachnaharry, on south side of Loch Clunie, 2 or 3 miles west of Glendoe.

19. (1) In Stratherrick, a large patch of grey granite rocks occurs. They are extensively quarried, and therefore are easily recognisable. Blocks have been carried eastward, even to near Elgin. They occur also on the tops of the Conglomerate hills between Loch Kecklis and Loch Ness, at heights of from 1400 to 1500 feet (*Jolly, in Fifth Report*, p. 72).

(2) Along north bank of Loch Ness, near east end, a patch of red granite occurs, blocks of which have been recognised in the Tomnahurich gravel hill near Inverness, and even on towards Nairn and Forres (*Fifth Report*, p. 69).

Along south bank of Loch Ness, near east end, a peculiar liver-coloured Conglomerate rock occurs, blocks from which seem identical with a number of large boulders east of Inverness (*Fifth Report*, p. 71, and *Sixth Report*, p. 47).

The late George Anderson of Inverness states that in some of the drift deposits near Inverness there are pebbles and boulders "that appear to have come from very distant parts of the country. Such," he says, "are the white stone of Ben Nevis and of Strathconon

(Ross-shire), and the quartz rock of Foyers" (*Wernerian Trans.*, vol. iv. p. 205).

Mr Jamieson of Ellon adverts to this same drift accumulation, known as Tornain Hill, in the following terms:—"There are masses of coarse water-worn gravel rudely piled together, 200 feet thick. The stones are all water-rolled, and show no glacial striæ. The pebbles are of various kinds of metamorphic and crystalline schists, red sandstones, conglomerates, granites, and porphyries. These materials look as if derived from the rocks along the valley to the south-west" (*Proceedings of the London Geological Society*, January 11, 1865).

(3) In town of Inverness, a boulder of greenstone or black granite, called "*Clach-na-Cudaine*"—"*Stone of the tub*," now standing in High Street, with pillar on it supporting town armorial bearings. Stone had formerly stood at top of cliff above River Ness, and from time immemorial afforded a convenient rest for the tubs or pitchers in which the women brought up water for household use. When a supply of water was brought into the town by pipes, the magistrates proposed to break up the boulder, but the townspeople objected at first even to its removal. A compromise was come to by the boulder being shifted to the side of the street, opposite to the Court-House, and by the erection on it of the Town Arms (*First Report*, p. 18).

(4) At *Clachnaharry*, a boulder weighing about 100 tons, called "The Watchman's Stone," resting on a projecting part of the coast (opposite to Inverness), from which a good view can be had of Moray and Beauly Firths.

Above Clachnaharry there are smoothed rocks, with grooves running E. and W., a direction parallel with Beauly valley.

(5) *Culloden Muir.*—Here stands "The Duke of Cumberland's Stone," a Conglomerate boulder with six sides, height about 6 feet, and girth not quite 60 feet. Its longer axis W.N.W. On top of boulder traces of striæ running W. by N. Boulder lies on an extensive plateau about 450 feet above the sea. At nearly the same level a horizontal terrace is visible, looking south, on the hills to the south of the River Nairn, about two miles distant (*Second Report*, p. 158).

There are no Conglomerate rocks, except on Loch Ness, which bear W.N.W.;—or at Kilmorack (on River Beauly), which bear N.W., each place about 20 miles distant.

Craig, Parish of.—About half a mile S.W. of village, a mica schist boulder, 17 × 8 × 9 feet. It lies on hills sloping down N.W.

There is also a Conglomerate boulder known by name of "*Tom Riach.*" Its west side 18 feet, north side 21 feet, east side 24 feet, south side 21 feet, and height 20 feet—652 tons. Boulder rests on gneiss rock. Lower surface seems smooth, as if it had been pushed over hard materials. Boulder has by some means apparently come down the valley of the Nairn, viz., from westward (*Second Report*, p. 158).

On plateau, 4 miles south of Inverness, at about 774 feet above sea, another Conglomerate boulder, with thin stratum of Old Red Sandstone on its top. Its girth about 51 feet, height 9 feet. Longer axis N. and S. A kaim of gravel and sand, about 900 feet above sea, situated north of boulder, running E. and W., or parallel with Nairn valley, on north side of which it occurs (*Second Report*, p. 158).

(6) *Dallanossie Parish.*—Boulder (apparently coarse granite) 30 × 18 × 9 feet (360 tons), on Dallry Farm, Moy estate. Boulder split into two parts, which gives its name, viz., "*Clach Schuilt*," or "*Cloven Stone.*" Height above sea 2090 feet (*Captain White of Ordnance Survey*).

(7) *Duntelchak Hill*, west of Inverness, about 900 feet above sea, composed of coarse Conglomerate. On N.W. side rocks are ground down and smoothed; on S.E. side rocks rough and steep. Granite boulder, 7 × 4 feet, lies on N.W. slope of hill, about 30 feet below top. Longer axis N.W., with sharp end towards that quarter. No granite rocks in this district except to west, about 10 miles distant.

(8) *Flichity Valley* (about 8 or 9 miles S.W. of Inverness), through which River Nairn flows.

An isolated hill on south side of valley, about 1620 feet above sea, well covered with boulders, which are precariously situated on account of steepness of hill-side (*Lithograph* No. 32, Plate X.). They are chiefly on west slopes.

On this hill there are horizontal terraces, with boulders on them.

At east end of Flichity valley a great embankment, which, before being cut through by River Nairn, must have been the means of forming a lake filling the valley. The cut across this embankment, through which river flows, is about 200 feet deep.

There are also in the upper part of Nairn valley many large gneiss boulders, supposed by Mr Jolly to have come from the west, several of which are split; one at height of 2260 feet above sea-level.

At *Farr*, in Nairn valley, to the east of the embankment, and near junction with another valley which runs N.W. up to Duntelchak, there

is a remarkable assemblage of gneiss or mica slate boulders (*Lithograph* No. 34, Plate X.). They were first pointed out to the Convener by Mr Jolly. Some rest on glaciated rock surfaces, sloping down to westward, and which therefore suggest transport of the boulders from westward.

Reasons given for suggesting first a glacier, which passed down eastward, and subsequently a submergence of the land under the ocean (*Second Report*, p. 159).

(9) About 6 miles S.W. of Inverness, an extensive plain, about 645 feet above sea-level, covered with drift, on which several Conglomerate boulders occur. They probably came from Duntelchaig and other hills to westward. One is 24 × 21 × 8 feet—340 tons. Longer axis W.N.W.

On "*Craig-a-Clachan*," at a height of about 1100 feet above sea, a large Conglomerate boulder called "*Watch Stone*"—made known to Convener by Mr Jolly. It lies on gneiss rock, and on very edge of a precipice of 100 feet vertically below it, on its N.E. side. In order to reach a site in this position it could have come in no other way than in a direction between W. by N. and W.N.W., and almost certainly on floating ice.

On the same hill there are other boulders of smaller size, whose position in like manner suggests transport from westward.

(10) Some miles farther south there is a lake bearing name of "*Loch Clachan*," probably on account of the number of boulders on its banks and the hills adjoining. Most of these are of grey granite.

By reference to Professor Geikie's Geological Map of Scotland, it will be seen that the nearest position for granite rocks in this district is Loch Faraline, about 15 miles westward.

One of these boulders is 21 × 20 × 14 feet (218 tons) at 983 feet above sea. Another about same size, and at about 1259 feet above sea has its sharp end towards west. The east end is broad, and butted up against a gneiss rock, which would obstruct its passage eastward. On this gneiss rock there are E. and W. striæ, which might have been made by the boulder pushing and pressing hard pebbles over the rock.

(The facts given in (9) and (10) are taken from Convener's *Treatise on Ancient Water Lines*, pp. 86, 87.)

(11) *Craig Phaedrich Hill*, consisting of Conglomerate rock. On its N.W. slopes the rocks are bared, rounded, and smoothed, with boulders of gneiss lying on the N.W. slopes. Hardly any boulders or striated rocks are on south slopes of the hill.

On several parts of the hill, especially on its south slopes, the rocks are broken up into large cubical fragments, resembling, in shape and composition, the boulders mentioned in (5) above (*Second Report*, p. 163).

(12) In the *Ninth Report* (pp. 10–12) there is an interesting list of boulders in the neighbourhood of Inverness by Mr Wallace, High School, Inverness.

(13) *Kingussie.*—On Clunie M'Pherson's lands, two boulders of a coarse-grained granite. One is 11 × 9 × 6 feet, the other is about double the size of the former, with felspar crystals of a green colour, and mica plates about 1 inch square.* Longer axis of both, about E. and W. Both lie on a hill-slope, facing down west. Height above sea 1035 and 1080 feet. Rocks of district are clay slate.

The nearest hill is *Craig Dhu*, situated 4 miles to north on opposite side of Spey, the rock of which is also clay slate.

Another boulder on Belville estate, 2 miles from Newtonmoor Railway Station, from 950 to 1000 feet above sea. Greatest length 14 feet, breadth at top 8 feet, height 9 feet. Longer axis S.S.W.

At *Laggan* Free Church, a well-rounded granite boulder, 9 × 6 × 6 feet, with longer axis E. and W., corresponding with directions of numerous striæ on a well-smoothed rock on which boulder lies.

Nearest hills of granite are some miles to the west.

Kincardineshire.

1. *Banchory-Devenick*, near Glassel Railway Station. Boulder called "Bishop's Stone"; circumference 44 feet, height above ground 8 feet, estimated weight 70 tons. Bluish granite, differing from adjoining granite rocks. An ancient stone circle of boulders about 200 yards distant.

About 2 miles to north, rocks on Hill of Farre glaciated with striæ, running E. and W.,—parallel with axis of Dee valley.

Fettercairn.—No boulders now in parish, of any size. Long banks of sand and gravel, running parallel with one another.

2. *Maryculter.*—Boulder $5\frac{1}{2} \times 6 \times 6$ feet. Longer axis N. and S. Rock of boulder supposed to be same as rocks to eastward (*First Report*, p. 40).

* The only other boulder with felspar and mica crystals, similar to those met with by Convener, is that mentioned as occurring on Treshlik Hill, p. 63.

KIRKCUDBRIGHT.

1. *Galloway.*—Great accumulation of boulders at head of valley, at Loch Narroch. Among these are boulders of the peculiar graphic granite of Loch Eroch to the north, so that these must have been carried southwards across various ridges and valleys to places where now found.

Craiglee, remarkable for numbers of perched blocks, some of immense size; their numbers on a long ridge of hill resemble a broken-toothed saw.

Travelled blocks occur, even on summit of Merrick, highest hill in Galloway (2764 feet). A number of poised blocks, and "rocking stones" (*First Report* p. 40).

2. *Kells.*—On Craigenbay Farm, a grey whinstone boulder 17 feet long and 10 feet high, 800 feet above sea. Longer axis N. and S.

3. *Kirkbean.*—On sea-shore at Arbigland, grey granite boulder $16 \times 9\frac{1}{2} \times 7\frac{1}{2}$ feet (about 80 tons), resting on sandstone rocks.

Criffel Hill is about 3 miles to N.N.W. Rock there, same as boulder. In all the glens between Criffel and sea-shore numerous granite boulders, generally arranged in lines parallel with glens.

4. *Penninghame.*—Granite boulders chiefly; supposed to have come from Minnigaff Hills situated to N.E. Some large boulders on watersheds between Lochs Dee and Troul.

5. *Twynholm.*—Granite boulder supposed to have come from Galloway Hills, 6 or 7 miles to westward. Several Druidical circles here.

6. *Borgue.*—Boulder of red syenitic granite; oblong in shape. Longest axis N.W. Rests on low hill of decomposed trap. South-east end vertical and rough. Girth at 3 feet above base 23 feet. No granite rocks nearer than about 10 miles, viz., a range of hills between Dalbeattie (east of boulder) and Creetown (west of boulder). Sketch of boulder given (*First Report*, p. 40).

7. *Generally.*—Large rounded fragments of granite and syenite abundantly scattered over *Stewartry*, and so arranged as to indicate that they have been dispersed by some force proceeding from N.W. (*Sixth Report*, p. 27; *Highland Society's Trans.*, vol. viii. p. 716, *Hay Cunningham*).

Professor Harkness, in the year 1870, made known to the London Geological Society his discovery of Criffel granite boulders in *Cumberland.* In his paper (published in the *Quarterly Journal* for November 1870, p. 522) he states that "this Criffel granite occurs

not only in the form of blocks on the *surface*, but also in the *boulder clays*." The Criffel granite blocks are also common in the *boulder clays* of the vale of Eden. He adds that there are also "*Eskars* in the valley, which yield blocks of Criffel granite."

In the Ninth Report of the English Boulder Committee, an account is given of the boulders found while excavating for the new docks at Maryport, on the south side of the Solway; among them were granite blocks, varying in size from pebbles to blocks of a ton. It is remarked in the Report that "the nearest granite occurs in "Kirkcudbrightshire Hills, 15 or 20 miles distant, nearly due north."

In the Fifth Report of the English Boulder Committee (*Br. Ass. Pr.* for 1877, p. 82) there is notice of a Criffel granite boulder found near Liverpool in excavating for new docks. It is added "that Mr J. Geikie and Mr Horne pronounced specimens which were sent to them to be from the outskirts of the Criffel granite area."

There is ground for believing that Criffel granite boulders occur even so far south as Lancashire. Mr Mellard Reade of Liverpool, C.E. and F.L.G.S., wrote in the course of 1882 to the Convener, that having for some years, while investigating the drift deposits near Liverpool, collected specimens from boulders, some of which were evidently derived from rocks different from any belonging to that part of England, he wished to submit these to any person known to the Convener to be well acquainted with the rocks of the S.W. of Scotland. The Convener having suggested Mr Dudgeon of Cargen, Dumfriesshire, Mr Reade transmitted the specimens to him, the result of which is explained in the following extract of a letter from Mr Reade to the Convener—

"Mr Dudgeon recognises with certainty Criffel granite, having assured himself of its identification by having seen in some of the specimens submitted to him the minerals sphene and allanite, which he is not aware occur in any other granitic district nearer than Aberdeenshire and Sutherland. He also thinks some of the granites come from veins in the Silurian rocks about 7 miles from Dumfries." *

* Mr M. Reade has since (Feb. 1884) read in the London Geological Society a paper narrating a visit he made to Kirkcudbrightshire, for the purpose of comparing chips from the Lancashire boulders with the supposed parent rocks. In this paper he mentions his identification not only of granite boulders with the rocks of Criffel and Cairnsmore of Fleet, but also of Liverpool Silurian boulders with Kirkcudbrightshire rocks. When his paper was

Lanarkshire.

Glasgow.—(1) Near Possil, sandstone rocks under boulder clay, striated, partly from N.W. partly from N.E., oldest apparently being from N.W., judging by length and depth of striæ. Boulders in the clay, recognised by Mr John Young of Glasgow University Museum, some from Kilpatrick Hills to N.W., and others from Campsie Hills to N.E.

(2) At Brickwork, near Garscube Road, sandstone rocks, also striated from N.W., and more deeply than at Possil.

At this place, numerous boulders of old red conglomerate, grey granite, schists, &c., supposed to be from Bonaw and Kilpatrick Hills to N.W. (*Second Report*, p. 165).

Linlithgowshire.

1. *Bonnington District.*—(1) On Pumpherston estate, the "*Ballengeich Boulder*," in girth 10 or 12 feet; but now broken up into eight fragments. It is a coarse dolerite, of which no rocks nearer than Bathgate Hills, about 2 miles to N.W. Had been about 60 tons in weight. The boulder was lying on boulder clay.

Not far from this boulder there is another of quartzite, about a quarter of a ton in weight, and containing crystals of green mica, most probably transported from Highlands.

(2) On Tornain Hill, Bonnington Farm, occupied by Mr James Melvin, another dolerite boulder, known as the "*Witch's Stone*," about same size as that at Pumpherston, and about same height above sea, viz., 431 feet. It lies on a slope which faces W.N.W. On digging below the boulder, Mr Melvin found it resting on decomposed trap. Nearest rock of same kind is on Bathgate Hills, situated 5 miles W.N.W.

There is a valley between Tornain Hill and Bathgate Hills, across which boulder had probably been transported. If a line be drawn from this boulder to Bathgate Hills, it passes close to "*Ballengeich*" boulder.

This boulder also has been broken into six fragments. Some archæological interest attaches to boulder, as on one of its fragments there are "cup markings."

(3) Formerly, on S.E. side of Tornain, another dolerite boulder,

read he exhibited chips from these boulders and the parent rocks for comparison. In this paper there is a becoming acknowledgment that Mr Mackintosh had been the first to refer the Lancashire granite boulders to Criffel (*L. G. S. Trans.* vol. xl. p. 270).

21 × 5 × 4 feet, lying with longer axis E. and W., and at height of about 300 feet above sea. If it also came from Bathgate Hills it probably had to come by floating ice, round Tornain Hill, by valley between Tornain Hill and the Crow Hills.

(4) In channel of River Almond, below Kirkliston, a boulder of Old Red Sandstone conglomerate, $5\frac{1}{2} \times 4\frac{1}{2} \times 4$ feet; nearest rock for which, is at Callander, about 40 miles to N.W., with several valleys and ranges of hills between.

(5) At Ratho Railway Station, rocks smoothed and striated on west sides, the direction of the striæ being W.N.W. (*Seventh Report*, pp. 23, 24).

2. *Kirkliston.*—The remarkable stone known to archæologists as the "*Catstone*," bearing a very ancient Latin inscription, which the late Sir James Y. Simpson deciphered, is described by him as "a massive unhewn block of secondary greenstone, many large boulders of which lie in the bed of the neighbouring river." The block is 7 feet 3 inches in length and 12 feet in circumference (*Proc. of Society of Scotch Antiquaries*, vol. iv. p. 122).

Midlothian or Edinburghshire.

1. *Pentland Hills.*—The late Charles Maclaren was the first who described e boulders on these hills. The one of most interest is of mica slate, weighing 8 or 10 tons. The nearest spot from which it could have come is at or near Loch Vennacher or Loch Earn, about 80 miles to the N.W.

With reference to the transport of this boulder, Mr Maclaren says:—"To reach the spot where it lies, it must have passed over extensive tracts of country from 500 to 600 feet lower than this spot. Even were all Scotland converted into a *mer de glace*, like Greenland, no moving mass in the shape of a glacier could carry this boulder (and there are many such) from its native seat in Perthshire or Argyleshire to Habbie's Howe. An iceberg from the North or West Highlands, and floating in a sea 1500 or 2000 feet above the present level of the Atlantic, is an agent capable of effecting the transportation of the stone, and offers, I think, the only conceivable solution of the problem" (*Edin. New Phil. Journal*, 1846, p. 138). Referring to this boulder, and to another, also of mica slate, on the Pentlands, weighing about three quarters of a ton, the late Professor

Nicol remarked:—"When it is considered that these masses must have been carried upwards of 40 miles in a direct line, floating ice seems the only agent to which their transportation can be ascribed" (*Lond. Geol. Soc. Journal*, vol. v. p. 23). He adds:—"Some of these Pentland Hill boulders are of *kinds of rock which I have never seen in Scotland.* On one hill, 1500 to 1600 feet high, I found these travelled stones particularly abundant, and apparently increasing in number from below upwards. In some places they appeared to form broad bands, running nearly in straight lines from N.N.W. to S.S.E.,—and without any reference to the present declivity of the ground,—except becoming more numerous towards the summit of the ridge" (*Sixth Report*, p. 26).

A number of rock surfaces occur on the Pentlands with striæ. Mr James Croll, of the Scotch Geological Survey, describes one of these on the very summit of Allermuir Hill, at a height of 1617 feet above the sea. On examining the striæ he says he had no "difficulty in determining that the ice which effected them came from the *west.* On the summit of the hills we found patches of boulder clay in hollow basins of the rock. Of one hundred pebbles collected from the clay, every one, with the exception of three or four composed of hard quartz, presented a flattened and ice-worn surface, and forty-four were distinctly stratified. A number of these stones must have come from the Highlands to the N.W." (*Fifth Report*, p. 82).

In like manner, Professor Geikie, in his interesting *Memoir on the Geology of the Neighbourhood of Edinburgh*, observes that "boulder clay lies along the N.W. flanks of the Pentlands, rising to a level of at least 1300 feet. When the clay has been removed, we usually find the rocks below polished, grooved, and scratched, in a direction nearly E. and W. or E.S.E. and W.S.W. The parallelism of the striations throughout the present district shows that the floating ice must have moved in a pretty uniform direction; and that it was from the *west*, is rendered clear, by the striation of the western faces of the hills, by the great depth of drift on their eastern sides, and by the fact that the transported boulders, when traceable to their parent rock, have been carried from W. to E. The drift in this district indicates a period of slow submergence, which went on until probably every hill had sunk far below the sea-level, and when ice-borne blocks from the snow-covered islets of Isla or the

Grampians, were dropped on the submarine slopes of the Pentlands" (*Memoir* No. 33, p. 127) (*Fifth Report*, p. 18).

2. *Edinburgh and Suburbs.*—The late Charles Maclaren, in his *Geology of Fife and the Lothians*, published in 1838, refers to boulders which he found on or near Arthur's Seat, the Castle Hill, and Calton Hill.

On *Arthur's Seat*, about twenty or thirty boulders are specified up to 30 tons, most of which he identified with rocks situated to the west of the boulders. Others (of sandstone) he found at much higher levels than any sandstone rocks now on the adjoining hills (p. 64, 2nd edition).

To the east of the *Castle Hill*, numerous boulders are mentioned as having been found to the eastward, which are with good reason referred to the Castle rock; but other boulders are mentioned (p. 91) as having been found on the west side of the Castle rock, which must be referred to some more distant locality.

It is right for Convener to notice a *Conglomerate boulder* standing on a stone pillar in the public gardens at the foot of the Castle rock. It was brought there as an ornament to the gardens by Mr Henderson, nurseryman, who had been entrusted by the magistrates with the arrangement of the gardens. He had found it in his own Nursery Gardens, Leith Walk. It is probably a true erratic, hailing from Callander.

On the Calton Hill, boulders are mentioned by Mr Maclaren as found there, "of the very peculiar syenitic greenstone of Corstorphine Hill" (p. 72).

In the year 1847,* a new road (at the expense of Government), was made round Arthur's Seat, which required an excavation to be made on the S.W. side of the hill, between the main body of the hill and an outlying knoll known on account of its basaltic columns as "*Sampson's ribs*," at height of 390 feet above the sea.

The hollow between the hill and the knoll was excavated to a depth of 20 or 30 feet, in order to lessen the steepness of the road. Thereby a trough or gully, with rocky sides sloping steeply towards the axis of the gully, was disclosed. The axis of the trough was about N.W. and S.E.; its length about 120 yards; its width at the narrowest part where the road was made, about 10 yards. As the rocky sides of the gully sloped down towards the

* The particulars here given will be found in a paper by the Convener published in the *New Edinburgh Philosophical Journal* for January 1847.

axis, these sides would probably meet below; but the excavation for the road did not reach that point. The gully had been filled with till, and contained numerous boulders,—almost all of which were found to be different from any of the rocks on Arthur's Seat, viz., felspar, greenstone, porphyry, limestone (both lacustrine and marine), quartz, greywacke, with fragments of shale and coal.

Many of these blocks were found in contact with both sides of the gully. The largest blocks were near the north end. The large blocks were well rounded; the small blocks less so. One large boulder on the west side of the gully appeared to have been pressed against the rock there, and had stuck in that position, being rounded and also partially striated on its N.E. side,—an indication of the friction it had undergone, by materials forced through the gully from a N.W. direction.

The gully was not throughout of equal breadth; at its narrowest point, the sides (when the boulder clay and drift were cleared away) were found at one place to be about 15 feet nearer one another than elsewhere. The rocks on the east side had been ground down, smoothed, and striated, some of the striæ being continuous for nearly 6 feet, and $\frac{1}{3}$ of an inch deep.

Generally, the striæ were horizontal; but at and near the narrowest part of the gully the striæ were seen to rise up at an angle of 4° or 5°;—caused probably by the obstruction to the drift when being forced through the gully.

One peculiarity in the striations deserves notice, as showing the direction from which the striating agent moved. The striæ were most numerous and deepest on the east side, suggesting that the striating agent had moved in a direction from a more westerly point than N.W. The rock surfaces facing the S. and S.W. were neither striated nor smoothed.

There is another spot, on the south side of Arthur's Seat, worthy of notice, on account of the boulders there, and the position occupied by them. It is on the west side of Windy Gowl. When the new road was being made there, a thick bed of clay and sand, in stratified layers, was exposed to view. In this bed, many blocks from the overhanging rocks of the hill were found embedded. The bed of sand and clay had been *formed round these boulders*, showing

that after they fell sedimentary matter brought by water had been deposited. The largest of the blocks was round and smooth on its west side, rough and angular on its east side. Besides the blocks of stone, which were of the same nature as the rocks of Arthur's Seat, there were in this bed of sand and clay blocks foreign to Arthur's Seat (brought from the west probably), viz., red compact felspar, red syenitic porphyry, marine limestone, and clay ironstone.

At Easter Duddingstone the excavations for the North British Railway exposed a number of large boulders embedded in the stiff blue till. Two of the boulders were of Old Red Sandstone Conglomerate—one an old porphyry, one a black basalt—rocks not existing in the immediate neighbourhood, but belonging to localities in the far west. Most of them were on their upper surfaces flat, smooth, and striated, the striæ running in directions varying between N.W. and W.N.W.

At the sea-shore, between Joppa and Magdalen Bridge, the Convener examined many large boulders sticking in the blue till, most of them flattened on their upper surfaces with striæ pointing N.N.W. Several presented smoothings and furrows on their west sides, none on their east sides. One of the boulders presented two sets of striæ—one running N.N.W., the other running W. by S., the former partly obliterated by the latter, which therefore must have been the more recent.

3. *Dalmahoy.*—Two boulders, one $13 \times 10 \times 6$ feet, and the other $10 \times 8 \times 5$ feet, lie at the side of the Water of Leith. The longer axis of both is E. and W. Both were covered with striæ also running E. and W. (*Sixth Report*, p. 27).

4. *Craiglockhart.*—Excavations were made in boulder clay for a hydropathic establishment. A number of boulders were seen by Convener in their original undisturbed positions. There were several of sandstone. The contractor for the building, having his attention drawn to these by the Convener, was asked if he knew any locality where there was sandstone rock of the same variety? He said that the sandstone rock quarried extensively at Hailes and at Redhall was exactly the same. On being asked to indicate the situation of these quarries, he pointed in a direction N.W. (by compass), distant about a mile.

5. *Tynecastle*, in west suburbs of Edinburgh.—A basaltic boulder examined by Convener and Mr Stevenson, C.E., $4\frac{1}{2} \times 4 \times 2$ feet, buried in a knoll of muddy sand, discovered on removal of the knoll. The sand contained numerous pebbles of all kinds, hard and soft, such as quartz, shale, coal. Height above sea 200 feet. Sides of boulder well rounded. Smallest end of boulder pointed westward. Both *upper* and *under* sides of boulder striated. Striæ more deeply cut on under than on upper surface. The striæ on under surface showed they had begun to be formed at east end of boulder, probably by the boulder having been pushed towards *east*, over hard rocks. The striæ on upper surface showed that the tools which formed *them* had acted on the boulder first at west end.

6. *Granton.*—The sandstone rocks at the *Old Quarry* near the sea were covered by boulder clay, which had embedded in it many blocks derived from Linlithgow and Stirling shires. The striæ on their upper surfaces all run E. and W., viz., a direction parallel with the general axis of the Firth of Forth (*Edin. New Phil. Journal* for January 1847).

At *Granton Harbour*, on the west side of, at the shore, there are two large whinstone boulders, with striæ on their upper surfaces, the direction of which is W. 3° S. (magnetic).

7. *Leith Docks.*—In new Albert Docks excavations were made in the boulder clay, in course of which a number of large boulders were found.

They consisted mostly of blue whinstone, also some of quartz, limestone, greywacke, sandstone, and black ironstone concretions derived from beds of coal and shale. On most of the boulders there were smoothed surfaces and striæ, bearing nearly the same direction, viz., points between W. and N.

Among these there were two *metallic* boulders, which, having a strange appearance, were brought to the Convener by the Inspector of Works; and to Professor Crum Brown (of Edinburgh University), the Convener submitted them for examination. One, nearly spherical, measuring $7\frac{1}{2}$ inches in circumference, and weighing 26 oz., had been found about $4\frac{1}{2}$ feet down in the clay bed, among the general mass of boulders. The other, more exactly spherical, measured in girth 30 inches one way and 31 inches transversely, and weighed 54 lbs. It was found 10 feet below the top of the boulder clay bed.

Professor Crum Brown having analysed both balls, reported the largest to have a specific gravity of 3·36, and to be composed of silica 52·3 per cent. and of pyrites 47·7 per cent. The smallest had a specific gravity of 4·63, and was found to consist of the pure ore of *white iron pyrites* or *marcasite*, unmixed with any other substance.

Mr Murray, of the "Challenger" Expedition, having kindly undertaken to examine the larger ball, reported that a microscopic examination revealed that it consisted "of crystalline particles of quartz and marcasite. The marcasite fills the interstices between the grains of quartz; and among the quartz there are pieces of mica."

Mr Charles Peach at the same time informed the Convener that in several districts to the west (viz., Falkirk, Slamannan, and Kilsyth) there are beds of shale and coal, containing ironstone nodules, known among the miners as "*brassy balls*," some of which contain *marcasite*. He added that "the direction of the *striæ* and *carry* of the boulders in this (the Kilsyth) district is E. or E. 5° N. Either of these sources (he remarked) could supply "*balls*" at Leith, as they are right in the direction of the "ice-flow" (*Fourth Report*, p. 29).

In consequence of the foregoing information, the Convener went to Campsie (about 8 miles N.E. from Glasgow), and in the workings of coal and shale there he obtained several ironstone balls, which, on being submitted to Professor Crum Brown, he reported contained almost exactly the same constituents as the specimens found at Leith. He added, that "deducting the coaly matter, the iron and sulphur were in the proportion in which they are generally found in marcasite, viz., iron 45·6, and sulphur 54·8. As to chemical compositions, therefore, the small metallic boulder may be considered as exactly agreeing with the nodules found in the Campsie coal strata."

With regard to the larger ball, not so purely metallic, Mr Hutchison of Carlowrie having accidentally seen in the Convener's house, Edinburgh, the specimen excavated from the Leith boulder clay, informed the Convener that balls of the same appearance, and much larger, were found in sandstone rocks quarried at Dalmeny and Humbie. The Convener thereupon visited these quarries, and

saw several specimens of such balls, apparently concretions in the rock. Having brought one or two specimens to Edinburgh, he submitted them to Professor Crum Brown, who reported that they "consist externally of a thin shell of sandstone, and internally of a mixture of quartz and marcasite, closely resembling the substance of the large ball from Leith. The mean specific gravity of the ball was 3·49."

These facts regarding the two metallic boulders found in the Leith boulder clay, therefore afford strong presumptive evidence that they had been transported across Scotland, along with other bouldres, whose parent rocks occur also in the west.

As to the mode of transport, Mr Peach, in his letter to the Convener (printed on p. 29 of *Fourth Boulder Report*), whilst allowing that the balls might have come from Kilsyth or Slamannan, in conformity with the general "direction of the striæ and *carry* of the boulders in this district," viz., E., or E. 5° N., suggested "*ice-flow*" as the medium of transport, but without explaining whether he meant sea ice or land ice.

With reference to this question, it is right to keep in view that the Campsie district, from which the metallic boulders are assumed to have come, is only 150 feet above the present sea-level; and that, as this district is about 30 miles distant from Leith, the gradient would not be sufficient for the movement of a glacier, even if there had been mountains at or near Campsie sufficiently high to have generated a glacier.*

8. *Alnwick Hill, near Liberton.*—Excavations having been made in the boulder clay here, for the formation of large water reservoirs, innumerable boulders were excavated. They were chiefly whinstones, felspar, porphyries, limestones, and Old Red Sandstone—all most probably from the N.W.

Some of these boulders showed striæ both on the under and the upper sides, the direction of which was approximately N.W. (*Fourth Report*, p. 29).

Inchkeith.—The Convener visited the island, under the guidance of Colonel Muggridge, R.E., and found that the rocks consist chiefly of basalt and porphyry, intruding among coal strata. In various

* A small map of district, given afterwards in reference to Stirlingshire boulders, may here be referred to.

places, the rocks were covered by beds of boulder-clay, gravel, and occasionally sand.

The Inspector of Works informed the Convener, that at the east end of the island, when removing a bed of shingle (about 60 feet above the sea), he had picked up out of the shingle two pebbles of *red granite*, about the size of a hen's egg. Thinking it curious to find granite there, he had laid them aside, but could not now find them.

The Convener, having been informed that there was a shingly beach at the N.W. end of the island, descended to it, and found large pebbles of granite (both red and grey), gneiss, quartz, and hard Silurian rocks.

On the highest part of the island (west of the Lighthouse) at 182 feet above the sea, the rocks on portions of the hill facing the N.W. have been planed down to even surfaces by some agency from the W. No striæ were distinguishable (*Sixth Report*, p. 26).

Morayshire.

Dyke.—Near west end of approach to Darnaway Castle several boulders of granite and gneiss, from 2 to 3 tons each.

Forres.—Conglomerate boulder, $9\frac{1}{2} \times 8 \times 8$ feet, weighing about 44 tons. It is situated on hill side fronting Cromarty, which bears N.W. by N., from whence boulders are supposed to have come across the Moray Firth.

Convener heard of another boulder of same description in a higher part of the hill, to the eastward.

Elgin.—Boulder called "*Carlin's Stone*," on Bogton Farm, about 230 feet above sea; a coarse Conglomerate. About half a mile to N.W. a smaller Conglomerate boulder, called "*Young Carlin's Stone*" (*First Report*, p. 31, and *Second Report*, p. 152).

There are no Conglomerate rocks in the low-lying districts, where these boulders are situated. Wherever they have come from, they must have been *carried.*

Conglomerate rocks exist in the hills to the south, distant 5 or 6 miles. Convener was informed by Mr Martin, teacher, Elgin (well acquainted with the rocks of the district), that the Conglomerate *formations* in the hills are, in mineralogical composition, distinguishable

from the Conglomerate *boulders* in the counties of Moray, Nairn, and Banff. Two other sources were considered by him more probable—Cromarty to the N.W., and the hills near the east end of the Caledonian Canal.

Throughout the county there are hundreds of rounded boulders of granite, gneiss, and mica slate, whose shape suggests that they have been pushed or rolled over the surface. These are chiefly embedded in gravel, clay, and sand.

Pluscardine Hill has had lodged on its north slope a number of boulders which have apparently come from N.W. There is a gneiss boulder, 13 × 8 × 6 feet, about 46 tons, called "*Chapel Stone*," situated to west of Pluscardine Chapel; also a Syenite boulder, 12 × 8 × 3 feet, about 13 tons. The rocks *in situ* here are Old Red Sandstone.

Carden Hill forms a rocky sandstone range running about E. and W. Between it and Pluscardine Hill, there is a shallow valley, through which boulders may have been rafted to their present sites in an easterly direction. The two Carlin Stones might have come that way.

The rocks along ridge of Carden Hill, have been ground down by some agent which has passed over it from N.W. Many boulders of granite and gneiss lie on the ridge, most of which have longer axis N.W. by W. Some lie along ridge, on its northern edge, apparently stopped there in their farther progress; others lie on south side of ridge, as if pushed over it, and placed beyond reach of transporting agent.

Blocks of the Carden Hill sandstone rock are also there, as if broken off the ridge by the agent which passed over from north. The ridge of Carden Hill extends for about a mile, and is at a height of 400 feet above sea.

Many smoothed and striated surfaces are visible, the direction of the striæ having been observed at different places as follows:—W. by N.; W.N.W.; N.W. by W., and N.W. The most frequent direction was N.W. At one spot, striae observed N. by E., and crossing the N.W. striæ; the forming appearing, therefore, to have been first formed (*Second Report*, p. 154).

Quarrywood Hill, about 200 feet above the sea, composed of sandstone rocks. On N.W. slope there are four or five large Conglomerate boulders, about 140 feet above sea-level.

Burgh-head.—Rev. Dr Gordon of Birnie conducted Convener to Clarkeley Hill, on which several granite and gneiss boulders were found lying on slope of hill. One has its longer axis N.W. and S.E. Several others showed *striæ* in same direction.

On Roseile estate here, "*Hare*" or "*Witch Stone,*" a Conglomerate boulder 21 × 14 × 4 feet, with longer axis N.W.

Inverugie Lime Quarries.—Limestone rocks striated in an E. and W. direction. In boulder clay here, boulders of oolite found, which must have come from Ross or Sutherland shires.

Duffus Public School.—Convener had shown to him portion of an oolite boulder found here, 125 feet above sea.

"*Witch Stone,*" a large Conglomerate boulder, at 250 feet above sea, on hill-side sloping down to N.W. It is exactly similar to "*Carlin's Stone,*" in respect of nodules of granite, gneiss, or purple-coloured quartz contained in it. Its longer axis is N.W. and S.E. It lies on a thick bed of sand.

Lossiemouth.—About 1½ mile west of Covesea lighthouse, a large boulder of silicated sandstone, on a hill sloping to N.W., with striæ on boulder running N.W. and S.E.

On old sea margin, 20 feet above present sea-level, a Conglomerate boulder, same in composition as Carlin Stone.

New Spynie.—Four Conglomerate boulders, lying on Old Red Sandstone rocks.

Llanbryde, St Andrews.—Gneiss boulder called "*Grey Stone,*" 15 × 9 × 7 feet, about 70 tons, lying in bed of old Spynie Loch.

Rothes.—Convener informed by Mr Martin, teacher, of six hornblende boulders, lying on gneiss rocks (*First Report*, p. 31).

Between Forres and Nairn there are extensive beds of sand and gravel, mostly in stratified beds, and containing boulders almost always rounded. The angular boulders are generally on the surface, not so embedded.

Nairnshire.

Croy.—"*Tom Riach,*" boulder of Conglomerate.—See Inverness county, under head of "Inverness and Croy" (*First Report*, p. 43) (*Lithograph* No. 35, Plate X.).

Cawdor.—On hill of *Urchany*, composed of granite, at levels above sea, of from 300 to 700 feet, four immense Conglomerate boulders

with popular names, described in *First Report*, p. 42 (*Lithograph* No. 34, Plate X.). There are granite rocks in hills to south, on which blocks of Old Red Sandstone lie, and in such quantities that they are gathered for the building of walls. These blocks probably came from the north, where there are rocks of the same kind (*First Report*, p. 42, and *Second Report*, p. 166) (*Lithograph* No. 36, Plate X.).

On "*Piper's Hill*," where rocks are Old Red Sandstone, a Conglomerate boulder, weighing about 10 tons, lies on the N.W. side of a gravel kaim. These Conglomerate boulders are all mineralogically similar, being composed of quartz, limestone, syenite, felspar, and other hard angular pebbles. Most of them are partly buried in sandy drift. The district on which they lie slopes down towards N.W., and is about 200 feet above sea, from which distant about a mile.

The longer axis of these boulders is chiefly N.W., and on that side they present smooth surfaces, whilst east side is rough and angular (see Diagram 8 in *Second Report*, and p. 166, and also *First Report*, p. 42).

Captain White of Ordnance Survey informed Convener that, having tried to find out where these boulders came from, he was of opinion that they had come from Ross-shire.

He reported also having met with granite boulders (both red and grey varieties)—the largest $12 \times 8\frac{1}{2} \times 8$ feet, and with longest axis N.W.

A kaim of gravel and sand, with steep sides, runs on an average E. and W. through parish, but occasionally deviates slightly from this direction. Its average height above adjoining district is 30 feet (*Second Report*, p. 166).

Ardclach.—In Bog of Fortnightly, about 5 miles distant from the sea, and about 270 feet above it, a Conglomerate boulder with five sides, having girth of 51 feet, and 9 feet above ground. The block is scarcely rounded at its edges and corners, and therefore has probably been *carried*, not *pushed*, *rolled*, or *thrown* down, but planted gently on its site. It is smoothest on N.W. side, roughest on S.E. It is surrounded by hills on every side except towards N.W. (*First Report*, p. 42).

Kinsteary (about 2 miles S.E. of Nairn).—A peculiar flesh-coloured fine-grained granite rock is worked, blocks of which are stated by Mr Jolly of Inverness to have been transported eastwards

beyond Forres,—gradually lessening in size and numbers, reaching to Elgin, Lossiemouth, and even farther east. Pieces also occur on the shores of Loch Spynie (*Fifth Report*, pp. 74, 75).

Mr Wallace of Inverness mentions having found a specimen of this Kinsteary granite beside Buckie harbour, about 20 miles east of Lossiemouth (*Sixth Report*, p. 49), and he has seen many smaller specimens in the fields. Neither rock nor boulders of this peculiar granite have been found *west* of Nairn.

Northumberland.

In Chillingham Park (Earl Tankerville's seat), between Wooler and Alnwick, there is a large boulder of red porphyry, besides several small boulders of granite. The rocks there *in situ* are Carboniferous sandstones and limestones. The nearest localities for porphyry and granite are the Cheviot Hills, about 8 miles to W.N.W., which reach a height of 1800 feet above sea. Many ridges and valleys lie in the intervening district (*Fourth Report*, p. 34, and *Edin. Roy. Soc. Trans.*, vol. xvii. p. 35).

Orkney.

Eday.—Conglomerate boulder, about 8 tons, situated near top of hill, about 250 feet above sea, called "*Giant's Stone.*" Legend as to it having been thrown from island of Stronsay, where there are said to be Conglomerate rocks, of which none in Eday. Longer axis points S.W. and N.E.

Patrick Neill, in his *Orkney, Visit to,* at p. 38, refers to "the great *Stone of Eday,*" as "a huge flag rising about 16 feet upright in the midst of a moor."

Frith and Stennis.—Peebles of *white* sandstone lie on the hills. Rocks of island are all *red* sandstone.

Sanday.—Gneiss boulder about 14 tons. Rocks of island are Old Red Sandstone. At Stromness, 30 miles to S.W., gneiss rocks occur *in situ.* A legend that the boulder was thrown by a giant from Shetland (*First Report*, pp. 10, 44).

The late Dr Patrick Neill states that, if this boulder came from Stromness, it would have to cross several arms of the sea in a distance of 34 miles, from W.S.W. (*First Report*, p. 44, and *Second Report*, p. 167).

Stromness.—Two granite boulders lie on Old Red Sandstone, near Manse. Range of granite hills 6 miles long, situated to eastward (*Second Report*, p. 169).

Walls (in south end of group).—Lydian stone boulder, weight about 28 tons. Large numbers of granite boulders scattered over hills. The valleys show (in opinion of reporter, James Russell, teacher) both glacier and iceberg agency (*First Report*, p. 44).

In a paper on the "Glaciation of the Orkneys," by Messrs Peach and Horne of the Government Scotch Geological Survey (*London Geological Society's Journal* for November 1880), it is said that "boulders do not occur very plentifully." The only island in which boulders are mentioned as seen by them, is *Westra*, where "blocks of granite and quartzite are on the slopes of Cleat Hill; and rounded boulders of red sandstone from *Eda* occur in the southern district, as well as along the western shores." Messrs Peach and Horne state "that the only part of the Orkneys which has granite or other crystalline rocks is at *Stromness*, where they form a strip about 4 miles long by 1 in breadth." If the *Westra* boulders came from Stromness, they must have been transported about 40 miles in a N. or N.N.E. direction, across what now is occupied by several groups of islands and deep sea sounds.

If, on the other theory, the boulders of sandstone on the southern and western shores of *Westra* came from *Eda* (as suggested in the above passage), they must have been transported about 10 to 12 miles in a N.W. direction, across what is now a sea sound, in some places 25 fathoms deep.

Messrs Horne and Peach, in the memoir now referred to, referring to the beds of red boulder clay in the islands of *Eda, Sanday, Stromsa, and Shapinshay*, mention that in these clay beds there are boulders smoothed and striated, most of them "*foreign to the islands*," and in many cases, accompanied by "*numerous fragments of marine shells;*"—"these fragments being smoothed and striated like the stones in the boulder clay,"—"characteristics, which (they say) there can be no doubt are due to the very same cause in both cases" (pp. 656, 657).

North Ronaldshay.—Boulders foreign to the island mentioned (*Eighth Report*, p. 7).

In *Ninth Boulder Report* (p. 20) there is a further account of

blocks of stone, foreign to the rocks of the island, viz., Conglomerates, granite, syenite, chalk, oolite, limestone, and sandstone.

In Ronaldshay boulder clay, containing these blocks, there are fragments of *Cyprina Islandica*, *Astarte*, *Dentalium*, and other marine shells.

The *Conglomerate* boulders are supposed to have been carried from the adjacent island of *Sanday;* the blocks of *granite and syenite* from *Stromness* and *Pomona*, distant about 45 miles to S.W.

Messrs Horne and Peach (*Journ. of Lond. Geol. Soc.* for Nov. 1880) mention that in Stronsa Island (not far from Ronaldshay) there is a bed of clay, 20 to 30 feet thick, containing granite, gneiss, oolite, and chalk flints, &c., all foreign to the island, besides fragments of marine shells.

Mainland.—Mr Miller of Ben Scarth reports a valley bissecting the island, which he thinks was formerly an arm of the sea. The lochs of Stennis and Stanay now occupy it.

No *large* boulders; but on north exposures of hills there are small stones strewed over the surface, quite different from rocks *in situ.* The former are chiefly white freestone; the rocks Old Red Sandstones or flagstones (*Second Report*, p. 167).

Messrs Peach and Horne express an opinion that all the boulders in the Orkneys, as well as in the Shetlands, were carried or pushed across the islands by a Scandinavian ice sheet from the S.E.

Objections to that theory were suggested by the Convener, in articles which appeared in the *Geological Magazine* for 1881, and in an address by him to the Edinburgh Geological Society in May 1881.

In addition to the foregoing notes respecting Orkney boulders, it is proper to notice the researches of Messrs Peach and Horne.

In a paper, published in the *Journal of the London Geological Society* for November 1880, it is mentioned, as the result of their survey, "that the islands have been glaciated in one determinate direction, independently of their physical features. When we consider that the glaciated surfaces along the cliff tops, as well as the *roches moutonnées* on the hill-slopes, prove that the *islands must have been overflowed by ice*, we cannot resist the conclusion that the ice

movement during the primary glaciation *originated beyond the limits of Orkney*" (p. 654).

"From the manner in which the rock striations maintain their N.W. bend, *irrespective of the physical features of the country*, it is evident that the agent which produced them must have acted *independently of the islands*" (p. 660).

Peeblesshire.

Kirkurd.—Three boulders of gneiss or trap, differing from rocks of district (*First Report*, p. 44).

Newlands.—Remarkable kaims (*First Report*, p. 44).

Peebles.—At east end of town boulder of white quartz, $3 \times 2\frac{1}{2}$ feet, used to stand in field, to which it gave name of "White Stone Knowe,"—alluded to as a boundary stone in year 1436.

Mr Richardson, of Edinburgh Geological Society, who was the first to take public notice of the boulder, states that "the nearest beds of quartz are about 80 miles to the N.W." Height above sea 550 feet (*Fourth Report*, p. 31).

The late Professor Nicol refers "to boulders of gneiss, granite, and mica slate in *Peeblesshire*, which belong to rocks unknown in the hills of that county;"—and adds, "they seem to require for their transport more powerful agents than mere currents of running water" (*Sixth Report*, p. 28).

Perthshire.

Aberfeldy.—(1) On north of Tullypowrie village considerable numbers of schist boulders—rocks *in situ* being clay state. Boulders well rounded, as if rolled. One of them called "*Clach Chin'uin*," or "*Stone of Doom*" (*First Report*, p. 45).

(2) Two miles N. of Tullypowrie, two very large boulders of mica slate at about 1500 feet above sea, shown to Convener by Mr M'Naughton, merchant.

They rest apparently on drift. Cubical in form. One found to be 71 feet in girth, and 17 feet high, weighing about 600 tons. Surrounded by hills on north and west, which overtop boulders by about 700 feet. But N.W. from boulders there is a depression in hills,

summit level of which only about 200 feet above boulders. Through this gap boulders may have come; but boulders are so cubical and sharp in angles that they must have been very gently lodged in present position. If they had fallen from any height they would have been fractured. These boulders have popular name of "*Clachan M'had*," or "*Stones of the Fox*" (*First Report*, p. 45).

(3) Above Pitnacree House, schist boulder resembling hypersthene, $15 \times 11\frac{1}{2} \times 4$, differing from all rocks near it, called "*Clach Odhar*," or *Dun Stone*."

Auchtergaven.—Granite boulder, $10 \times 8 \times 3$ feet, weighing about 8 tons, about 200 feet above sea, called "*Deil's Stane*." Longer axis N.E. Numerous cup markings on it. Supposed to have come from hills 30 miles to north.

Aberfoyle.—Arndrum Hill is a ridge of the Conglomerate rocks which cross Scotland from Dumbarton by Callander in an E.N.E. direction. On this ridge near Aberfoyle (230 feet above sea) there are six boulders of greywacke, forming a line bearing N. and S.—each about 3 cubic yards in size, and from 2 to 20 feet apart from each other. To the west of this line of boulders, four other similar boulders lie *along* the ridge, stretching to nearly top of hill, viz., to 454 feet above sea (*Ninth Report*, p. 16).

Blairgowrie.—Seven boulders of granite and mica schist, about 200 feet above sea. No rocks of same kind nearer than Braemar range of hills, about 30 miles to N.W.

Callander.—Gneiss boulder on top of Bochastle Hill, called "*Samson's Putting Stone*," resting on Conglomerate rocks. Longer axis N.E. In a very unstable position, being close to edge of a precipice. facing W.S.W., and about 330 feet above valley. About 50 feet below the above boulder there is another gneiss boulder, lying on a very steep slope of the same hill, facing westward,—from which quarter it must also have probably come (*First Report*, p. 46, and *Second Report*, p. 169) (*Lithograph* No. 37, Plate X.).

Clunie.—Several boulders on tops of knolls. They probably have come from Grampians, which lie to N.W. (*Second Report*, p. 170).

Crieff.—Two large Conglomerates, one called "*Witches' Stone*," and two of granite, one called "*Cradle Stone*," lying on the "*Knock*" Hill (*First Report*, p. 467).

Doune (near Kilbride).—A large Conglomerate boulder, weighing about 900 tons (*First Report*, p. 46).

The nearest Conglomerate rocks *in situ* are W.N.W. from boulder, and distant about 7 miles. The boulder in shape is angular. It lies on gravel. The boulder must have been *carried* to its site (*Estuary of the Forth*, p. 41).

Dunblane.—Gneiss boulder on Cromlix estate, about 4 miles south of Grampians, 17 × 10 × 5 feet. Longer axis S.W. and N.E. In *Redgorton parish*, four boulders (at west end of gravel ridge) reported to be Silurians; distant from Grampians 12 miles (*Third Report*, p. 5).

Dunkeld.—On Craigiebarns Hill, to N.E. of town, mica schist boulders, lying chiefly on knolls and other exposed surfaces which face N.W. at a height of about 1000 feet above River Tay.

On this hill, rocks smoothed and striated, by some agency which evidently passed over them from N.N.W.

The directions of the striæ at lower levels correspond more with axis of valley, which is about N.E.

The highest striations seem to indicate an agent which passed obliquely across the valley (*Second Report*, pp. 170, 171).

Fortingall.—Gneiss boulder, 24 × 16 × 13 feet, called "*Clach an Salaine.*" Height above sea, 2500 feet. Longer axis N.W. Composed of six or seven large fragments, weighing about 300 tons. Rests on coarse gritty sand. Rocks *in situ* clay slate. About 500 feet below boulder, thick beds of clay, sand, and gravel, denoting aqueous agency (*First Report*, p. 46, and *Second Report*, p. 172).

Fowlis.—Several granite boulders near Abercairney, lying on Old Red Sandstone. Have come most probably from N.W., in which direction, at a distance of about 20 miles, there are granite rocks. Supposed to have been used as places of worship and sepulture in ancient times (*First Report*, p. 47, and *Second Report*, p. 171).

Killiecrankie.—A large angular limestone boulder, half a mile north of Tenandry Manse;—believed to have come from *Ben-y-Gloe*, or some other mountain adjoining to the north.

On Fascally estate, immense beds of stratified gravel and sand (filling the valley, and cut through by mountain torrents), traced by Convener up to height of 1570 feet above sea. He was told by Rev. Mr Grant of Tenandry of there being similar beds at

a still higher level on *Ben-y-Gloe.* Boulders of granite, gneiss, quartz, porphyry seen by Convener in the Fascally drift-beds (*Second Report*, p. 172).

Killin.—On hill to west, about 1350 feet above Loch Tay, thick beds of gravel and sand; and therefore about 1650 feet above sea (*Second Report*, p. 173).

On *Morenish*, east of Killin, and about 1100 feet above Loch Tay, several large boulders (*Fourth Report*, p. 31), of which sketch given. These, as shown by positions, have all come from westward.

Kilspindie.—Seven granite boulders, from 5 to 6 tons weight. Five form a line, having a N.W. direction, all differing from the adjoining rocks (*First Report*, p. 47).

Kirkmichael.—Rocking Stone, $7 \times 5 \times 2\frac{1}{2}$ feet, and several tall boulders near it, called "*Clachan Sleuchdaidh*," or "*Stones of Worship*" (*First Report*, p. 47).

Logie Almond.—A whinstone boulder called "*Ker Stone*," about 48 tons in weight, on north bank of River Almond, near a bog; "*Carr*" being Gaelic for "*Bog.*"

There is another boulder, a Conglomerate, resting on Old Red Sandstone, called "*Cul na Cloich*," or "*Stone Nook.*" A stream forms a nook or angle with the drum or ridge, on which boulder stands.

Another Conglomerate boulder on Risk Farm (*First Report*, p. 47).

Glen Dochart.—The axis of valley is about E. and W. On its slopes facing the north, and near bottom, there are many large boulders of granite, which may have come from Ben Cruachan. They occur also on the ridges, on south side of valley;—some so placed as to show transport from westward.

At height of 1250 feet above sea, a vertical rock, well smoothed, with horizontal groovings on its west and north sides, indicative of some agent which has pressed severely on it in passing from westward (*Fourth Report*, p. 32) (*Lithograph* No. 38, Plate X.).

Schehallion Mountain (top of, 3560 feet above sea).—Gravel beds indicative of aqueous action, seen by Convener, up to about 3000 feet, to which height small blocks of a fine-grained grey granite seen. Side of hill with smoothest rock surfaces looks N.W. by W. No striæ seen (*Second Report*, p. 173).

Mr Jamieson of Ellon states (*Quart. Journ. Lond. Geol. Soc.* for

1865, p. 165) that *Schehallion* is marked on top, as well as on its flanks, by traces of ice passing over it from the north.

He further states, that along the *north* slopes of the great ridge of mica slate, stretching from *Schehallion* in an E. and W. direction for 10 miles, he saw many boulders of *granite* and *porphyry*, at heights exceeding 2000 feet, above the sea;—the one at the highest elevation, being a granite boulder, at an elevation of 2370 feet. On the ridge where these boulders lie there are no granite or porphyry rocks; but such rocks do occur to the northward (as in *Glen Tilt*), where, therefore, probably is the source from which the boulders came (*Seventh Report*, p. 40).

On the Perthshire Hills, between *Blair Athole* and *Dunkeld*, Mr Jamieson found ice-worn surfaces of rock on the tops of hills, at elevations of 2200 feet, as if caused by ice pressing over them from the N.W.;—and transported boulders at even greater heights.

On the highest watersheds of the *Ochils*, at altitudes of about 2000 feet, Mr Jamieson found pieces of *mica schist* full of garnets, which seemed to him to have come from the Grampian Hills to the N.W., showing that the transporting agent had overflowed the Ochil range (*Seventh Report*, p. 42).

Pitlochry.—On road to Straloch, a mica slate boulder, about 8 tons weight, called "*Gledstone*," about 1800 feet above sea, lying on gravel drift; adjoining rocks are clay slate. Legend that this boulder gave name to Gladstone family, an infant having been found at boulder by shepherd, who took it to his wife to be nursed.

Near parish church of Straloch, "*Clach Mhor*" (*Great Stone*), a boulder of coarse granite, about 24 × 20 feet, and weighing about 800 tons. Many other boulders of mica slate and quartzite beside it. Supposed to have come from the north, through a valley there. Adjacent rocks, clay slate (*First Report*, p. 47).

Luib.—Large boulders lying in a line along ridge and top of *Beinn nan Clach.* One, much rounded, on the solid rock of the very summit, 2309 feet above sea. Summit rock also much rounded. The outcrop of the strata on hill-side have been broken off by some means (*Ninth Report*, p. 13, and *Lithograph* No. 39, Plate X.).

Renfrewshire.

Kilbarchan.—A porphyry boulder, 27 × 17 × 12 feet, weighing

about 300 tons, called "*Clach a Druidh*" (*Stone of Druid*). Rocks of same kind as boulder in hills to W. and N. about 2 miles distant (*First Report*, p. 48).

Paisley.—Mr Jamieson of Ellon describes boulders in clay beds of brickworks. Many of these boulders show glacial striæ. It is common to find *Balani* sticking on under surface of these boulders. Suggested in explanation, that after *Balani* had grown on boulders, the boulders were floated away by ice, and dropped on mud where now found. Mr Jamieson adds that "I sometimes found, on heaving up a boulder, a number of young crushed mussel shells beneath it, as if squashed by the fall of the stone." The clay round also occasionally exhibits black stains, as if from the decay of sea-weed that had been attached to the stone" (*Lond. Geol. Soc. Proc.*, xx. p. 276 (*Seventh Report*, p. 43).

Ross and Cromarty.

Glenelg (West Coast).—On right bank of Elg, a grey granite boulder 21 × 18 × 10 feet, (280 tons)—its sharp end points N.N.W. (*Fourth Report*, pp. 3, 4).

Glen Rossdale.—About 8 miles from Glenelg, several boulders, which, on account of positions, seem to have come from the N.W. Ordnance surveyors reported several horizontal terraces among the hills of this glen, up to 800 feet above sea-level (*Fourth Report*, p. 49).

Lochalsh (West Coast).—Gneiss and quartz boulders. Longer axis of first, E. and W. ;—of second, N.W. and S.E. (*First Report*, p. 49).

Rosskeen.—Granite boulders of large size at Ardross, Newmore, and Achnacloich (*Second Report*, p. 175).

Shieldag (Loch Carron).—Boulder 18 × 10 × 10. Longer axis E. and W. ; also another. Both in precarious positions (*First Report*, p. 50).

Applecross (viz., on West Coast).—Three large boulders, one near shore at Rossel, called "*Clach Oiu*," weighing about 60 tons ; other two about 30 tons each, called respectively "*Clach Mhoir*" and "*Clach Bhan*" ;—used as landmarks from the sea. Kaims at Ardbain and Ardrishach, each extending more than 2 miles along coast (*First Report*, p. 48).

The late Professor Nicol notes that on the tops of the Applecross Hills there are boulders of large size. He says that the direction of the rock striæ there is S. 20° W. (true).

Gairloch (West Coast).—Numerous boulders were found by

Convener along coast to north of the Gairloch Hotel, and at all heights up to the very summits of the hills, reaching to nearly 1000 feet above sea. The late Professor Nicol's description of these boulders is not inappropriate, when he says that these "hills about Loch Maree and Gairloch are strewed with innumerable fragments of red sandstone, perched, like sentinels, in the most exposed and perilous positions, on the very edge of some lofty cliff, or on the polished summit of domes of gneiss." These red sandstone boulders belong mostly to what has been termed the Cambrian formation, reddish-brown sandstone rocks, which exist along the coast towards the north, and partially also in the east coast of the Lewis. The rocks of the Gairloch Hills are generally gneiss.

Lithograph No. 40 (Plate X.) represents a granite boulder on the edge of a high sea-cliff facing the west, 747 feet above the sea, projecting $2\frac{1}{2}$ feet beyond the edge of the cliff; having apparently been lodged there by some agent which, striking upon the cliff, caused the boulder to slide off upon the cllff.

Lithograph No. 41 (Plate X.) represents one of the hills on the coast, to the north of the Gairloch Hotel, 585 feet above the sea, with two boulders on the west side of its summit. The Convener, on ascending the hill to examine the boulders, found that the large boulder was 7 feet long by $3\frac{1}{2}$ feet high, and that it projected 2 feet beyond the edge of the cliff. As the rock on which it rests slopes down towards N.W. at an angle of 15°, the Convener thought there would not be much difficulty, by means of a crowbar, in projecting it over the cliff altogether.

Lithograph No. 42 (Plate X.) shows the foregoing boulder, with the rock it rests on, on a larger scale. This boulder is a blue whinstone, the small boulder a red sandstone, and the rock of the hill clay slate.

Lithograph No. 43 (Plate X.) shows a rocky knoll, near the base of the same hill, on which a number of true erratics are clustered. The uppermost of these (6 × 5 × 3 feet) rests on the others, in such a position as to show that it had come from the N.W.

On the hills between Gairloch and Loch Fionn, the position of the smoothed rocks, and also of boulders, seemed to indicate a movement rather from W.S.W. than from the usual direction of N.W. The deflection, the Convener thought, could be accounted for by a range of hills there, against which the transporting agent may have struck (*Fifth Report*, p. 56).

Loch Maree.—Rocks on road between Gairloch and Loch Maree showed striæ, in usual direction of W.N.W. and E.S.E.

Boulders are visible on all the hills. Near *Loch Maree Hotel*, at height of about 1000 feet above sea, a plateau found by Convener, well covered by boulders lying on drift.

On another hill near the hotel, about 900 feet above the sea, a well-rounded boulder was found, very near the top, on its west side, lodged in a shelf, where it pressed at its east end against the rock of the hill, as shown on *Lithograph* No. 44, Plate X.

Achnasheen (*Dingwall and Strome Ferry Railway*).—A boulder 15 feet in girth of grey granite, on a gravel terrace, 610 feet above sea. Locality interesting, on account of the immense beds of gravel and sand which have been formed here—no doubt by the agency of the sea; and probably flattened by lacustrine waters, of which Loch Rosque is a remnant.

Several hills to the south ascended by Professor Heddle;—one of them, *Sgurr-na-Lapaig* (3778 feet), requiring "the hardest climb" he had ever experienced. For about 1500 feet above "*Loch Mullardoch* the slope was at an angle of 47°. At height of 1530 feet there rests on this slope a boulder 12 × 8 × 7 feet, of hard quartzy gneiss, which he says *must* have been *brought* there," as it differs from the rock of the hill (*Ninth Report*, p. 16).

Ben Wyvis (3426 feet), near Dingwall.—Its N.W. shoulder presents whole acres of rock swept bare of soil, with rounded and polished boulders of a peculiar veined granite, identified with rocks to the westward, in the tract called *Dirriemore.* These boulders are found half way up Ben Wyvis. Similar boulders occur, strewed over the country both north (Alness and Ault Grand), and south (Strathgarve) of Ben Wyvis. In Strathgarve some of the boulders are as large as cottages (*First Report*, p. 48).

Dirriemore.—Mr Jolly of Inverness states that the peculiar *granite* of this district has been carried "*eastward*," none of it "*westward.*" It has been carried across the Cromarty Firth, and scattered in large masses even over the Black Isle. It is plentiful over the "*Laigh of Moray*" and along the sea-shore, between Burghead and Lossiemouth (*Sixth Report*, p. 47).

Mr Wallace of Inverness also reports having seen *Dirriemore*

granite in numerous boulders in the excavations for the new harbour at *Buckie* in Banffshire (*Sixth Report*, p. 49).

Edderton (west of Tain).—Three large boulders of *grey* granite pointed out to Convener at about 1000 feet above sea, on side of hills sloping down towards N.N.W. Rocks on which they rest are Old Red. A horizontal terrace is site of one. The idea that they came from "*Cairn na Cunneig*" (*Hill of Pitcher*), situated 12 miles to N.W. (as suggested by Rev. Mr Joass of Golspie), is disputed, as rocks there are stated to be a *red* granite. Another idea is that they came from hills near Rogart, 10 or 12 miles to N. or N. by E., as rocks there said to be *grey* granite (*First Report*, p. 49, and *Second Report*, p. 175).

Fannich Mountains (situated west of Ben Wyvis).—Mr J. F. Campbell (Islay) wrote to Convener that on these hills, 2700 feet above sea, there is a boulder of grey gneiss with garnets. Its local name is "*Clach Mhor na Biachdoil.*" It is 30 × 10 × 3 feet, and there is a train of large boulders to be seen in a valley not far off. Rocks smoothed and striated. Direction of striæ, parallel with valleys (*First Report*, p. 49).

Fodderty.—Boulder angular in shape, 14 × 8 × 5 feet. Looked on as Druidical. There is another with an inscription, which is supposed to commemorate a battle between two clans.

Tain.—Granite boulder, weighing about 60 tons, lying on Old Red Sandstone, about 2 miles N. of Tain at road side. "*Sir Walter Scott*" boulder of red granite, supposed to have come from "*Cairn na Cunneig*" mountains, situated to N.W. (*First Report*, p. 50).

Tarbet Ness.—"*Balnabruach*" boulder, a coarse reddish granite, 33 feet in girth and 9 feet high. Longer axis E. and W. This boulder, and another near it, not so large, supposed to have come from "*Cairn na Cunneig*" hill, which visible from boulder bearing W.N.W. and distant about 30 miles. A line from boulder to this hill would cross arm of the sea, 10 or 12 miles wide, between coast at Tain and Tarbet Ness (*First Report*, p. 80, and *Second Report*, p. 175).

Dingwall.—Mr Morrison, teacher in the Academy, and Secretary of the Ross-shire Field Club, sent notes, of which the following is an abstract:—

On the south slope of Tulloch Hill there are three boulders of a pinkish granite, of the following dimensions:—11 × 7 × 7 feet, major

axis N.N.W., at about 550 feet above sea;—8 × 5 × 5 feet, major axis N.N.W., at about 400 feet above sea;—a flat block of mica schist 11 × 7 × 2 feet, at 620 feet above sea, major axis E. and W. On this last-mentioned boulder there are ruts and striæ running N.W., and about thirty-six artificial cup-markings.

On Drynie Farm, S.W. of last mentioned boulder, at 610 feet above sea, a mica schist boulder 12 × 8 × 4 feet, major axis N.N.W. On its surface six striations, running N. and S., with one cup-mark at south end.

On Tulloch Hill, another pinkish-coloured granite boulder 900 feet above sea, 8 × 6 × 4 feet, with major axis N.W. The prevailing rock on Tulloch Hill is bluish-grey indurated sandstone slate.

Where strata crop out on opposite side of valley their edges have been rubbed and smoothed on their north faces by some natural agency moving in a direction from N.W.

On north slope of Tulloch Hill a moor stretches up to height of about 1100 feet, on which many small boulders of same kind as above,—and to be found also all the way down to Cromarty Firth.

Mr Morrison set out on an excursion to west, with the idea of discovering the direction from which these Tulloch boulders had come. At *Ach-na-Clerach* he found "a gigantic mass of the same kind of granite as the boulders, 25 × 23 × 12 feet,—the rock on which it was resting being different from that of the boulders.

At the confluence of the rivers *Glascarnoch* and *Strathvaick* he found rock of the same variety as the Tulloch boulders, but at a lower level than Tulloch Hill. He inferred that the boulders had been carried eastwards over the south shoulder of Little Wyvis, and that "*they* probably came from Carn-Cuineag through the opening occupied by Loch Glass."

Mr Morrison, accompanied by some geological friends, proceeded next to *Cairn Cunneag*, 2744 feet above sea. It is the highest hill in Easter Ross. Its two peaks, or *Pitcher lugs*, are pinnacles of granite. Its slopes are covered by enormous masses of granite semi-cubical in shape. An opinion was formed that most of the boulders in Easter Ross had been derived from this mountain, and its lesser neighbours *Carn-Maine*, and *Carn an Lochan.*

The saddle between the two peaks appears like a shingly beach;—rounded stones of about 10 pounds weight are packed here and

there in crevices, with longer axes of the stones lying generally in one and the same direction.

Roxburghshire.

Castleton.—Many blocks of granite (red and grey varieties) lie on greywacke and Carboniferous rocks,—which apparently came from Dumfries and Kirkcudbright shires, 30 to 40 miles distant, crossing Esk and other rivers (*Sixth Report*, p. 28).

Rounded boulders of grey granite occur on the fields and moors near Castleton Manse, where Convener saw several from 3 to 4 feet in diameter. On east bank of River Esk, about 2 miles below Langholm, Convener saw granite boulders—both red and grey varieties—some of them very large. A number occur also in the Gill burn, which flows into the Liddell above its junction with the Esk. These granite blocks lie on the greywacke strata, as well as on the coal measures. The nearest known hill of granite is Criffel, which consists almost entirely of grey granite, situated about 20 miles W.S.W. from these boulders. The next nearest place where granite rocks occur is in Ayrshire, at Loch Doune, bearing about W. by N. from the boulders.

In a small stream north of Tofts House, and about three quarters of a mile east of Edgerstone, there were seen by Convener several angular blocks of greywacke, resting on a purplish porphyry rock. The nearest point where there are greywacke rocks *in situ* is about half a mile to west, between which, however, and these blocks, there is a porphyry hill several hundred feet high. There is no greywacke to the south or east ("Geological Account of Roxburghshire," *Trans. Edin. Roy. Soc.*, vol. xv. p. 412).

In this parish there is a remarkable kaim, composed partly of gravel, partly of sand, in horizontal beds. It runs for about half a mile; is about 200 feet wide at base, and from 50 to 60 feet high. In the gravel there are blocks and pebbles of granite (both red and grey), as well as fragments of shale and coal,—derived, no doubt, from rocks to the westward. The kaim forms nearly a straight line, the direction of which is N.E. by E. (*Trans. Edin. Roy. Soc.*, vol. xv. p. 463).

Another long ridge of sand occurs near Eckford, on the River Cayle, running E.N.E.

Jedburgh.—Porphyry boulder, supposed to have come from Dunion Hill, which is 2 miles to the west. Formerly a Granite boulder on this hill (seen by Convener), which must have come from Galloway or Dumfriesshire (*First Report*, p. 50).

Nesbit.—Near the village (about 8 miles S.W. of Kelso) a greenstone boulder, identical in composition with rocks on Penielheugh Hill, on which stands Waterloo Pillar. Boulder is on a knoll, a little to N.W. of top of knoll. Penielheugh is S.W. from boulder, and about a mile distant. Transporting agent moved, therefore, here in a N.E. direction. Hill is 774 feet above sea, and boulder 224 feet above sea. Rocks where boulder lies are Old Red Sandstone.

Ruberslaw.—On this hill a large boulder of greywacke found by Convener, lying on Old Red Sandstone rocks. Nearest greywacke rocks *in situ* are about 3 miles to westward. If boulder came from these greywacke rocks it must have crossed low ground 800 feet below level of boulder (*Edin. Roy. Soc. Trans.*, vol. xv. p. 454).

Selkirkshire.

Galashiels.—On the top of Meigle Hill, 1430 feet above the sea, there is a Silurian boulder $6 \times 4\frac{1}{2} \times 3\frac{1}{2}$ feet, with its longer axis N.W. and its sharpest end pointing in that direction.

The boulder is on the east side of the apex of the hill, and 12 feet below it. It is lying on drift.

Meigle Hill is composed of Silurian rocks. It stands by itself; there being no hills of equal altitude within some miles of it.

Other boulders of a smaller size occur on the hill. They seemed to the Convener to be all erratics (*Sixth Report*, p. 30).

Shetland.

Brassay Island.—A number of coarse *white* sandstone boulders on east side of island, at heights of from 40 to 360 feet above the sea, differing from rocks *in situ*, which consist of Conglomerate and Old Red Sandstone flags. Largest boulder $10 \times 7 \times 4$ feet. Its longer axis N.W. There are said to be distinct groovings on it, some of them 3 inches deep;—their direction E. and W. Agent which striated rocks must in that case have crossed a valley at right angles (Dr Gordon of Birnie, Reporter) (*First Report*, p. 43, and *Second Report*, p. 176).

Foula Island.—Situated about 20 miles from nearest other island, and with a sound between, of 50 fathoms in depth (*Second Report*, p. 177).

On this island, which has on it a hill reaching to a height of 1370 feet, several boulders were reported to the Committee.

The Rev. James Russell, in 1873 (who was then resident in Walls), visited the island, and refers to several boulders—situated in the *south* half of the island,—the *north* half he had not examined.

From the middle of the island, to south end, he reported drift as high up as 700 feet, containing much granite and gneiss, which he supposed to have come from Mainland. In the *middle* of the island there are two boulders of irregular shape, each weighing about 2 tons,—their composition he does not mention.

Mr Russell stated that at the *south end* of the island there are three boulders of gneiss and two boulders of granite, each weighing from 3 to 5 cwt., and which he supposed came from the Culswick and Delting Hills on Mainland, towards the N.E.

Messrs Peach and Horne, on the other hand, suggest that these boulders may belong to rocks *in situ* on Foula itself, inasmuch as the eastern part of the island (they say) consists of gneissose rocks, with a mass of granite in the N.E. corner (*Geol. Mag.* for August 1881, p. 372).

Messrs Peach and Horne, however, mention that they discovered in the boulder clay of Foula a block of epidotic syenite from Dunrossness;—a locality which bears S.E. from Foula, separated by sea at least 50 miles in breadth, and having a depth of 70 fathoms.

Houssay Island.—On a cliff 200 feet above sea there are loose blocks resting on rounded and polished rocky knolls; the knolls having been evidently polished before receiving the boulders (*First Report*, p. 43).

Papa Stour Island was visited by the late Dr Hibbert in the year 1822 (*Edin. Journ. Science* for 1831, vol iv. p. 86). He found in it several peculiar schists, foreign to the island, apparently derived from rocks at Hilswick Ness, situated to the N.E., and distant about 12 miles across St Magnus Bay, which has a depth of 40 fathoms.

This island was visited also by Professor Geikie, who states that he found on it many "transported blocks of gneiss, schist, and other rocks foreign to the locality" (*Nature*, vol. xvi. p. 415).

Besides the boulders pointed out by Dr Hibbert, Messrs Peach and Horne say that on *Papa Stour* they saw others of "Old Red rocks, derived from the area occupied by the rocks between Sandness and Bixiter Voe;"—places on Mainland, situated to the S.E. of Papa Stour, and separated from it by an arm of the sea.

Hilswick Ness, the south end of an isthmus, on the north side of St Magnus Bay.

Dr Hibbert refers to a transported boulder on the summit of this promontory;—describing it as "a surprising block of granite;—removed from a rock, the nearest site of which is about 2 miles north" (*Edin. Journ. Science*, vol. iv. p. 89).

Messrs Peach and Horne, who had not mentioned this boulder in their paper, adverting to Dr Hibbert's notice of it, say that "this boulder might have been derived from some of the masses of the same material, lying at a slightly greater distance to the E. and N.E. of Hilswick" (*Geol. Mag.* for August 1881, p. 372). If that view be taken, the transport must have been across an arm of the sea running N. and S. on the east side of Hilswick Ness.

Roeness Hill, on North Mavine, 1476 feet high.—Dr Hibbert says, this hill being "composed of *red granite*, I was struck with the immense number of boulders of a *primary greenstone*, which appear to have been removed from a site 2 or 3 miles off, and to have been brought in a southerly or south-westerly direction up a gradual ascent of 3 or 4 miles (*Edin. Journ. Science*, vol. iv. p. 89).

Messrs Peach and Horne admit the facts as here stated. They say they "entirely support our conclusions, viz., of the boulder having been carried up hill by the Scandanavian ice-sheet, in a S.W. direction" (*Geol. Mag.* for August 1881, p. 371).

Additional Localities.—The Rev. Dr Gordon of Birnie visited Shetland in the year 1872, and sent to the Committee the following notes:—

(1) *Boulders.*—Near North Mavine (the extreme north of Mainland) there are large boulders between Hilswick and Ollaberry. He sent to the Committee pencil sketches of three boulders, situated in the same North Mavine district, between St Magnus Bay and Yell Sound. They are syenitic. One near Eela water is 16 × 12 × 6 feet. Another called *Crupna* (*bent*) is 11 × 8 × 8 feet. The third called *Bonhus*, situated between the other two, is 8 × 10 × 11 feet.

(2) *Striæ* on rocks seen by Dr Gordon, at two places, about 20 miles asunder; one a mile north of the fishing huts of Stennis on N.W. shore of St Magnus Bay, on coarse Conglomerate rock. The other place was at Islebury, where there is a valley running N. and S. The striæ showed that striating agent had crossed valley in E. and W. direction (*Second Report*, p. 177).

Lunnasting—Stones of *Stoffas.*—Specimens from these blocks were shown to late Professor Nicol of Aberdeen, who after examination considered them to be *gneiss*, the same as the rock of the island. They are from 20 to 22 feet high, and 90 feet in girth. Height above sea 100 to 120 feet. The Professor, from the account given to him of them, thought the stones had *probably* been "*carried*,"—there being no land near them at a higher level (*Second Report*, p. 193).

The following notes were sent to Convener, by some person, evidently well acquainted with the locality, but whose name has unfortunately not been preserved:—

Four boulders, looking "like pale granite," on the estate of *Lunna*. Nos. 1, 2, and 3 stand near each other in north part of parish, not far from sea, and at a height above sea-level of from 150 to 200 feet.

No. 1 is in height 22 feet; length, 36 feet; breadth, 25 feet, angular in shape; direction of longest axis N.W.

No. 2 is in height 19 feet; length, 34 feet; breadth, 14 feet; angular direction of longest axis N.E.

No. 3 is in height 11 feet 4 in.; length, 8 feet 7 in.; breadth, 8 feet 2 in.; direction of longest axis N.W.

Nos. 1 and 2 separated from each other by a distance of 10 or 12 feet; the intervening space *being filled* with large masses which have apparently fallen from No. 2.

Nos. 1 and 2, known as "*The stones of Stoffas.*" This word said to be a corruption of "*Stay fast*"; the legend being, that two giants were passing through Lunnaness, when some superior power arrested their farther progress by pronouncing the words, "*Stoffas!*"

No. 4 stands by itself, surrounded by deep moss, within a few yards of the highest point of a hill, about 4 miles to the south of the other three stones.

Note by Convener.—The stones of Stoffas are referred to by late Dr Hibbert, in his volume on Shetland. He describes them as "enormous detached masses, which do not seem to have undergone

any distant removal, since they repose on rocks of a precisely similar kind" (p. 179).

Professor Heddle of St Andrews informs Convener that he examined these stones, and thought they had been detached and wrenched off from other rocks, and moved in a direction towards E.S.E. (*Eighth Report*, p. 7).

Fair Isle Parish.—Rev. Mr Laurence, catechist, reported that there are no boulders above 10 tons, but that there are several small boulders of Conglomerate quite differing from any rocks in island (*Eighth Report*, p. 7).

He adds that there was one large block of sandstone which was blown up in 1880. It differed from any rocks in island, and was similar to the Eday sandstone.

The island of Eday is about 13 miles to S.S.W. of Fair Isle (*Eighth Report*, p. 8).

North Unst.—All over Unst the rocks show abrasion, and, in many places, deposits of drift, enclosing stones of various sizes.

Mr Peach, senior, at the request of the late Sir Roderick Murchison, examined this most northern isle of the Shetlands, and gave in a Report to the British Association in the year 1864. He stated that he "ascended the Muckle Heog Hill, reaching to a height of 500 feet; and found the W.N.W. end vertical, and polished to the depth of at least 150 feet." Professor Geikie in an article in *Nature*, of 17th September 1877, refers to the foregoing report by Mr Peach, and says "that from his own observations he can speak confidently as to the correctness of Mr Peach's determinations."

Sumburgh Head.—Conglomerate boulder lying on sandstone rocks (*Second Report*, p. 44).

In addition to the information in the foregoing notes, regarding boulders, it is right to refer to the information given by Messrs Peach and Horne (in their paper on the Shetlands) regarding the extent to which all the hills, even the highest, show traces of glaciation (*Jour. of Lond. Geol. Soc.* for November 1879).

They say—that "from Sumburgh Head northwards to Unst we found everywhere the clearest evidence that Shetland must have been at one time *smothered in ice*" (p. 706).

"It is apparent, on a moment's consideration, that the direction of

the striæ would have been widely different, had the island radiated *its own ice*, and had the glaciation been purely *local*" (p. 791).

"For these various reasons, we are justified in inferring that the glaciation of these outlying islets is due to the action of an ice-sheet *originating far beyond the sphere of Shetland*" (p. 792).

"The *highest ground in the centre of the Mainland* is likewise *ground down and striated.* The ridge which extends from Weesdale Hill (842 feet) to Scallafield (916 feet) reveals the fine lines as well the flutings of the ice-chisel" (p. 793).

STIRLINGSHIRE.

1. *Alloa.*—Basaltic boulder, 13 × 12 × 11 feet, called "*Hair Stone*," about 70 feet above sea. Longer axis N. and S. Assuming boulder to have come through valley or kyle, between Abbot's Craig and Damyat, it must have travelled in a direction from N.W. by W. (*First Report*, p. 50).

2. *Kilsyth and Strathblane.*—Mr Jack, of Scotch Government Geological Survey, reported two boulders,—one of mica slate, weighing about 6 tons, 1260 feet above sea, its parent rock supposed by him to be to the N., and distant 15 miles. The other boulder is Conglomerate, 8 × 4 × 3 feet, its longer axis being W. 20° N., its parent rock supposed by him to be also to N.W. (*First Report*, p. 51).

3. *Campsie.*—Mr John Young of the Hunterian Museum, Glasgow, accompanied Convener to an inspection of the district near Campsie, and pointed out the following objects of interest:—(1) On Craigend Moor, about 450 feet above sea, sandstone rock presented great sheets of smoothed surface, evidently ground down by severe or long-continued friction, with occasional striæ running S.E. by S. In some places there were quartz pebbles in the sandstone rock, which were ground down, showing marks of rubbing chiefly on the N.W. sides.

At four other places there were striations on rocks, pointing respectively S.E. by S. and S.E. ½ S., S.E. by S., S.S.E.

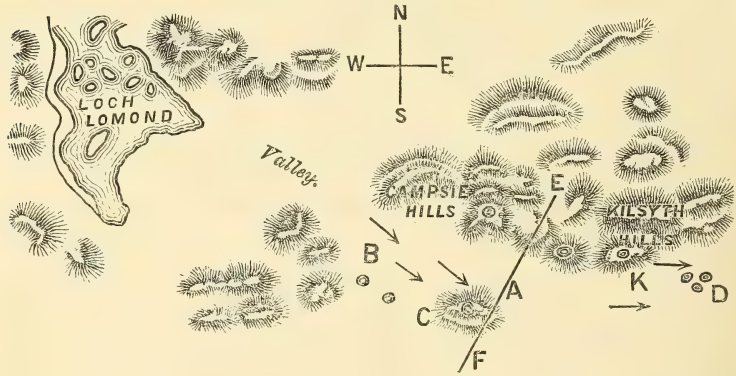
Looking from this moor towards the N.W., hills are seen about a 1000 feet high, at one place with an opening between them of about 1½ miles in width, through which, if there was a current, it might pass over Craigend Moor.

Several boulders were pointed out. Two were of a species of trap common in the Kilpatrick Hills, situated some miles to W.N.W. Another boulder was a grey granite, which, judging from the size of its felspar crystals, Mr Young supposed might have come from Ben Awe, a mountain situated to N.W., and distant about 30 miles. There were also several Conglomerate boulders, derived probably from the belt of that rock, which, running from Dumbarton, crosses Loch Lomond in a N.E. direction towards Aberfoyle.

The Convener at another time, when on Campsie Hills, found rocks at 800 feet above the sea, striated in a direction E. and W. On the Kilsyth Hills, a few miles further east, the rock striæ point the same way.

On *Croy Hill*, a knoll of trap rock, being the summit level between the Firths of Clyde and Forth, about 160 feet above the sea, there is an immense accumulation of boulders. Some of the boulders are of old Conglomerate, which must have come from the westward and stuck on the knoll (*Fourth Report*, p. 42).

The relative positions of these localities may be more readily understood, by referring to the annexed map.



⟶ Direction of rock striæ; B, Craigend Moor; K, Croy Hill; Boulders shown by black dots, • • •

4. *St Ninians.*—Boulder weighing about 200 tons, at height of 1250 feet above sea, reported by Mr Jack, but no particulars given (*First Report*, p. 51).

5. *Sheriffmuir*, 3 miles from Bridge of Allan, a large boulder called "Wallace's Putting Stone" (*Fourth Report*, p. 34).

6. *Stirling and Doune districts.*—Conglomerate boulders occur at the following localities (*Sixth Report*, p. 31):—

(1) At *Kilbride*, boulder of about 900 tons (mentioned under Perthshire).

(2) On *Landrick Estate*, boulder of about 360 tons.

(3) At *Keltie Bridge*, boulder weighing about 60 tons.

(4) On *Gartincaber*, boulder weighing about 16 tons.

(5) On *North side of River Teith*, boulder weighing about 13 tons.

(6) In the *Burn of Campsie*, two boulders each weighing about 13 and 24 tons.

(7) In the district traversed by the hill road between *Doune* and *Callander*, multitudes of smaller size.

(8) At *Cornton Brickwork* (between Stirling and Bridge of Allan), small boulder found in bed of clay.

(9) On the rocks adjoining *Stirling Castle* on the north, small Conglomerate boulders, besides others of gneiss and greywacke.

(10) At *Loch Coulter* and *Gillies Hill* (places 3 miles south of Stirling), several Conglomerate boulders, besides others of mica slate and felspar porphyry.

(11) On *Plean Estate* (4 miles S.E. of Stirling), boulders of Conglomerate, gneiss, granite, greywacke, and whinstone.

(12) At *Glenbervie*, near Torwood (5 miles S.S.E. of Stirling), a Conglomerate boulder, 6 feet square, found by Convener.

(13) On *Dunmore Estate* (9 miles S.E. of Stirling), a Conglomerate boulder of about 10 tons, found by Convener.

A more particular account of the foregoing boulders may be found in "*The Estuary of the Forth*,"* p. 41, where it will be seen, that all those which are elongated in shape, generally have their longer axis in a direction N.W. and S.E.

There can be no doubt that all these boulders had been carried from hills situated to the N.W., near Callander and Aberfoyle, as there are rocks there of the kind composing the boulders, and in no nearer district.

On the north side of *Stirling Castle* the trap rocks are traversed by narrow gorges, running about E. and W., the sides of which in many places present smoothings and striæ, especially on the south sides, indicating transport from a point a little to the north of west.

* Edmonston & Douglas, Publishers (1871).

The striæ are generally horizontal, but occasionally are inclined slightly upwards towards the east.

A few small boulders, well rounded, occur in several of the gorges. Among them, granites and conglomerates were observed.

Craigforth Hill, about 2 miles west of Stirling, has smoothings on its rocks near the top (198 feet above sea), and a few striæ running in a N.W. and S.E. direction. The Convener found on it also small boulders, apparently from rocks situated at or near Aberfoyle, which bears W. $\frac{1}{2}$ N. from Craigforth.

On or near the *Racecourse* at Stirling (situated S.W. from the Castle), about 130 to 160 feet above the sea, there are several granite boulders lying on smoothed sandstone rocks. The largest is $7 \times 3 \times 4$ feet. It is on a rocky knoll, the smoothest part of which slopes down towards N.N.W. As the boulder, from its composition, most probably came from the hills situated to the N.W., it must have lodged on what would be the *lee* side of the knoll.

7. *Aberfoyle.*—Arndrum Hill, reaching to height of 454 feet above sea, forms part of the ridge of Conglomerate rock, which traverses country in a N.E. and S.W. direction by Callander and Loch Lomond. On this ridge Professor Heddle, at a height of 230 feet, found a line of six boulders of angular gneiss, stretching N. and S. They are from 2 to 20 feet apart, and are from three-quarters to 3 cubic yards in size.

To the west of this line, four other similar boulders lay along the summit of the ridge, and thus at right angles to the first line (*Ninth Report*, p. 16).

Sutherlandshire.

Assynt.—Two large boulders, one at Unapool, the other at Stonechrubie, called "*Clach na Patain*" (*Stone of the Button*) (*First Report*, p. 51).

Golspie.—An Old Red Sandstone boulder, $16 \times 10 \times 4$ feet, about 248 feet above sea, lying on oolitic rocks,—subangular,—with longer axis N.N.W. Three smaller boulders of Old Red Sandstone lie about 100 yards to S.E. The Old Red Sandstone formation is situated to N. and W., about 3 miles from those boulders (*First Report*, p. 51).

Rev. Mr Joass, of Golspie, refers to a large boulder of gneiss, weighing about 120 tons, called "*Clach Mhie Mhios*"; *Clach* being

Gaelic for "*Stone*," "*Mhie*," of a *son*, "*Mhios*," of a *month;* this name having been given by legend, that stone was thrown from a hill 2 miles distant by a child of Fingal, when only one month old (*First Report*, p. 10).

West and North Coasts.—The late Robert Chambers visited the west coast of Sutherland, travelling round by Cape Wrath, and along the north coast as far as Tongue Bay, with the following results:—

1. At a height of 1700 and 1800 feet, he found striæ on the rocks of *Cuineag* and *Canish* (quartz hills in Assynt, about 30 miles north of Gairloch), running *from* about N. 60° W. with certain exceptions. One of these exceptions was at the base of *Cuineag*, where the streaks are from the direct *north*, apparently by reason of *a turn or deflection which the agent had there received at and by reason of the base of an adjoining hill.* Another exception was at the hollow dividing the mass of the hill from its loftiest top, where another system of streaking had come in from the direct *west.*

2. On a summit south from *Ben More*, fully 1500 feet high and 4 or 5 miles to the south of Cuineag, there are streakings on the quartz, observing the normal direction of this general movement, viz., from N. 60° W.

3. On the gneissic platform between *Coul More* and *Sulvean* Dr Chambers found polished surfaces striated from N.W. and from W. To the west and north of the latter mountain are markings in all respects similar. These are situations, observes Chambers, where no local glaciers could exist.

4. Streakings precisely the same as those on Cuineag and Canish exist at an elevation of at least 2000 feet on the similar quartz mountain called *Ben Eay*, south of Loch Maree, and 40 miles from Assynt;—this striation being from N.W. or thereabouts, and totally irrespective of the form of the hill.

5. Passing northward to *Rhiconish*, "we find near that place striæ *coming in from the coast*, viz., from the N.W., and passing across a high moor, with no regard whatever to the inequalities of the ground."

6. A little farther north, at *Laxford*, a fine surface is marked with striations from the N.W., *being across the valley in which is*

occurs. At an opening in the bold "gneissic coast, which looks out upon the *Pentland Firth,* there is strong marking in a direction from N.N.W. The high desolate tract between Loch Eribol and Tongue Bay, where there is *nothing that could restrain or guide the movement of the ice,* exhibits striations from N. 28° W. Striæ in nearly the same direction, viz., N. 25° W., occur 4 miles to the east of *Tongue.* On perfectly free ground, at *Armadale,* the markings point almost directly from the north. When we pass on to *Caithness* we find traces of striation, still from points between N. and N.W., which is directly transverse to a line pointing to the neighbouring hills" (*Fifth Report,* p. 62).

The late Professor Nicol observes that, "on the whole N.W. coast, from Cape Wrath southwards, numerous 'perched' boulders occur on summits and sides of hills, in most exposed situations. They are especially numerous around Loch Maree" (*First Report,* p. 51).

In another paper (*Brit. Assoc. Reports* for 1855, p. 89) the Professor states that "on the west coast of Sutherland, near Loch Laxford, enormous blocks are perched on the top of rounded bosses, or on the very verge of precipices. As the slightest impulse seems sufficient to dislodge these boulders, the manner in which they were placed in their present positions is very problematical."

It is matter of regret that no reports came to the Committee regarding the boulders on the N.W. and N. coasts of Sutherlandshire, though frequent applications for them were made. For want of reports it has been thought right to refer to the foregoing observations by Dr Chambers and Professor Nicol.

Clyne.—Remarkable kaims, apparently moraines, lateral and terminal, in Brora valley. At Clynlish quarry the sandstone rocks striated in a direction from W. by N. to N.W. (*First Report,* p. 51).

Wigtownshire.

Glasserton.—Granite boulder, 9 × 6 × 6 feet, weighing about 24 tons. Longer axis N.E. and S.W. Two other boulders in a line with it. These supposed to have come from mountains to N.E., crossing an arm of the sea.

Several kaims in the parish, full of granite pebbles (*First Report,* p. 38).

Glenluce.—The Rev. Mr Wilson reports the finding of water-worn nodules of *flints* in beds of stratified drifts, at different places along the coast for about 6 miles. Various localities named, where flints were found by Mr Wilson in drift beds up to 200 feet above sea. He suggests that some of the drift materials probably came from Arran, and the flints from Armagh in Ireland (*Ninth Report*, p. 26).

Faröe Islands.

Though these islands form no part of Scottish territory, they are not so far from the Hebrides, Orkney, and Shetlands, as not to warrant some notice of their glacial phenomena. Moreover, having been visited by several Scotch geologists, who reported on them to the Edinburgh Royal Society, it may be allowable to add a few notes bearing on the boulders and rock striations of these islands :—

I. *Erratics.*

1. The first traveller who noticed the glacial phenomena of the Faröes was the Rev. G. Landt, a Danish clergyman, whose book was translated into English in 1810.

In page 8 of his treatise he says :—

"There are sometimes to be seen in the *valleys*, *single stones*, 6, 8, or 10 feet in diameter, *in places where it is impossible they could have fallen down from the hills.* Such stones are found *also* here and there, at *a considerable height on the hills*, where there is no other eminence in the neighbourhood, from which they might have rolled down." He adds, a little farther on, that these "stones are generally round" in shape.

2. Dr James Geikie, in his elaborate and valuable *Memoir* on the Faröe Islands, lately published in the *Edinburgh Royal Society Transactions*, vol. xxx. p. 250, says, under the head of *Erratics*, that "*large angular blocks* of basalt rock are of common occurrence. Near Thorshavn, many are of large size, measuring occasionally upwards of 20 feet across. They occupy positions which preclude the possibility of their having fallen or rolled down the hills ; and as they are now and again associated with moraine debris, I do not doubt they have been deposited during the melting of the ice-sheet" (p. 250). . . . . "While perched blocks are quite absent from the

hill-tops, which give no evidence of glaciation, they are often scattered abundantly over the surface of high ground which has been glacially abraded. This is well seen upon the ridge between Gröth and Skeelfiork, where isolated erratics are sprinkled about upon the *moutonnée* surface" (p. 250). In the same paper, Dr Geikie elsewhere repeats that "the *large erratics* scattered over hill-tops and hill-sides were doubtless deposited by the *mer de glace* during its final dissolution" (p. 262).

II. *Rock Striæ.*

In the year 1812 Faröe was visited by Sir George Mackenzie and Mr Allan, both Fellows of the Edinburgh Royal Society, and both of them well-versed in geological inquiries. Both of them read to the Society accounts of their visit. Sir George, in his paper, expressed much satisfaction in having induced Mr Allan to be his companion, on account of "his great experience in geological examinations" (*Edin. Roy. Soc. Trans.*, vol. vii. p. 215).

Mr Allan, in his paper, refers more than once to a "headland near the village of Eide, which (he says) presents a perpendicular front to the ocean." So much interested was he in this "headland," that he attempted to measure its height, and found it to be 1134 feet (page 242).

In a subsequent passage, he again alludes to this "headland" as a thing "of interest," on account of the "remarkable instance (it presented) of the abrasion of its surface, where the rock appears to have been worn down by the friction of heavy bodies" (p. 244).

Then remarking that generally in Faröe, where the rocks do "not consist of impracticable cliffs, they present a solid, smooth surface, always highly inclined," he goes on to say, "it would be curious to investigate whether this smoothness on the sides of the mountains could be traced to any external cause, such as that which has been observed by Sir James Hall on Corstorphine Hill and other parts of the country, indicating the passage of heavy bodies along the surface. Near Eide I observed a very remarkable example of this description. There the rock was scooped and scratched in a very wonderful degree, not only on the horizontal surface, but also on a vertical one, of 30 to 40 feet high, which had been opposed to the

current, and presented the same scooping and polished appearance with the rest of the rock, both above and below."

In the year 1855 the late Robert Chambers, also a Fellow of the Royal Society, who had previously paid much attention to glacial phenomena, visited the Faröes, and wrote an interesting account of what he saw. He explains, that being aware of Mr Allan's discovery at Eide, he went there on purpose to study the markings on the rocks. The following is his description:—"There are some small fields under cultivation. Every here and there the rocks are presented on the surface, where they are invariably seen rounded or flattened, with peculiar deep channelings, precisely like those rocks which are now generally believed to have been abraded by ice. My attention being arrested by these features, I looked narrowly for the striæ or scratches which ice generally leaves on surfaces over which it has passed. They presented themselves in abundance, in several places, most strikingly of all, within sea-mark on the shore of the quiet bay, *being all directed from the north, which* is *also* the direction of the *canaux* or channelings, and further of the passage or isthmus in which the village (of Eide) lies."

In his *Memoir on the Faröe Islands*, Dr James Geikie (p. 246) referring to the same locality of Eide, says, that "perhaps the best preserved *roches moutonnées* we anywhere observed were in Osteröe and Sandöe. It was with considerable interest that we visited the northern portion of the former island, for we felt that the evidence to be gathered there would go a long way to settle the question which we had come to solve. No difficulty was experienced in finding the locality described so long ago by Allan, and subsequently visited by Chambers but the striæ, instead of being '*directed from the north*,' had clearly been graved by ice coming *from quite the opposite point of the compass.* The Kodlen peninsula we found glaciated all over, the *roches moutonnées* on both sides of the isthmus being beautifully perfect, and showing *Stogs* and *Leeseiten* in the most admirable manner. In many places the striæ are well seen, and long ruts and channelings, or grooves and trenches, well smoothed and ice-worn, traverse the rock surface. We traced the glaciated contour up to a height of 1302 feet, which was the summit level of the pass leading from Eide to Funding; but the

slopes facing the sound between Österöe and Stromöe seemed to be glaciated to a somewhat greater height. The direction of glaciation upon those slopes, so far as we could observe them, seemed to be in a direction corresponding with the trend of the sound, namely, from S.S.E. to N.N.W."

As any facts bearing on the smoothed and striated rocks at Eide and the Kodlen peninsula deserve attention, the following additional paragraphs in Professor Geikie's *Memoir* are quoted :—

On page 254 he states that "the soundings on the chart prove, that the long fiord which separates Stromöe from Österöe occupies the bed of two submerged valleys, with a low separating *col*, over which there is shallow water. This *col* occurs in the narrow part of the sound between Nordskaale and Öre; and the soundings show that from this point the water deepens, both towards N.W. and S.E. The fiord is shallower at its mouth near Eide, where there are $5\frac{1}{2}$ and 9 fathoms of water, than it is at and above Haldervig, where we get depths of 18 to 30 fathoms."

On page 261 Professor Geikie states that "the long sound that separates Österöe from Stromöe brimmed with ice, which flowed in two directions. North of Nordskaale the movement was northerly; while south of the shallow part of that sound the ice held on a southerly course."

A point, apparently of some importance, is brought out in Dr Geikie's *Memoir*, viz., that many of the hills show smoothing of rocks, only up to a certain height.

Thus it is stated that "the lower part of the mountains that overlook Kolfaredel are smoothed and abraded in a S.E. direction, and we estimated the height reached by the glacial outline to be some 1500 or 1600 feet. Above that level all is rough and rugged, and destitute of the slightest trace of glacial abrasion" (p. 245).

Then, on an adjoining mountain, where there is a pass at 1243 feet above the sea, there are "*roches moutonnées*," but we saw no striæ. The glaciated outline was continued up the mountain slopes above us, for not less than 400 feet" (p. 245).

In another locality, "the *col*, we found to be 1693 feet above the sea, and the glaciation came close up to this level. But abraded rocks with the characteristic glaciated contour certainly reached 1600 feet" (p. 246).

At p. 246 it is mentioned that "the upper parts of the hills between Fundingsfiord and Andafiord were above the limits of glaciation." . . . "Suderöe has supported a considerable mass of ice; for we traced the glaciated outline up to a height of 1040 feet. Above that level all is rough, angular, and serrated" (p. 248).

The explanation suggested by Dr Geikie of these interesting facts is, that "when the islands were enveloped in their ice-sheet, the action of frost would be confined to such ridges and hill-tops as projected above the *mer de glace*, while severe glacial abrasion would go on below" (p. 260).

Dr Geikie, in his *Memoir*, more than once takes notice of the "*scarcity of moraine mounds*," which, he says, "*it is difficult to account for satisfactorily*;"—but he offers under that head several suggestions, "the principal" being, "probably the continuous and comparatively rapid dissolution of the ice, after the snow-line had retreated several hundred feet above the sea-level" (p. 263).

LIST OF LITHOGRAPHS.

Argyleshire.

Plate VIII. No. 1. On west coast of Kintyre, a gneiss boulder, lying on Old Red Sandstone strata; blocked at south end, indicating probable transport from north. (*Abstract*, p. 773.)

Plate VIII. No. 2. View of a gneiss boulder jammed between rocky banks of a small stream. (*Abstract*, p. 774.)

Plate VIII. No. 3. Gneiss boulder, called "*Clach Udelain*" or "*Unstable Block*," in consequence of its precarious position. (*Abstract*, p. 774.)

Plate VIII. No. 4. "*Giant Putting Stone*," on rock smoothed from the north. Site of boulder on rock 18 × 12 inches. (*Abstract*, p. 774.)

Plate VIII. No. 5. Two boulders on similarly smoothed rock called "The Pig's Back," on Knap Farm. (*Abstract*, p. 774.)

Plate VIII. No. 6. *Loch Glashan.*—A boulder on Knock Farm, resting on smoothed rock, which dips N.N.E. at 30°. Longer axis of boulder and sharpest end point N. by E. (*Abstract*, p. 775.)

Plate VIII. No. 7. Three lithographs (1), (2), (3) of a boulder

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Plate VIII. No. 8. Great assemblage of boulders on south shore of *Loch Killesport.* B is boulder of 2770 tons weight. A is line of 40 feet old sea-cliff. (*Abstract*, p. 779.)

Plate VIII. No. 11. Rock smoothed and striated at Kilmory. (*Abstract*, p. 780.)

Plate VIII. No. 10. Cluster of boulders on steep hill-side, Killesport. (*Abstract*, p. 780.)

Bute.

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Hebrides.

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Plate IX. No. 16. *Iona.*—Granite boulder of about 400 tons, on plateau 230 feet above sea, leaning on west side of Dun I Hill. (*Abstract*, p. 809.)

Plate IX. No. 17. *Coll Island*, Bein Hock hill, showing N.W. front, with two boulders on summit, A B, and one on a plateau at its base, C. (*Abstract*, p. 811.)

Plate IX. No. 18. *Coll Island*, Grassipol meadow, having a vertical wall of rocks on S.E. side, showing a great accumulation of boulders. (*Abstract*, p. 811.)

Plate IX. No. 19. *Coll Island.*—A rocky knoll covered by boulders, showing that uppermost boulder had come from N.W. (*Abstract*, p. 812.)

Plate IX. No. 20. *Barra.*—Boulder of 890 tons, 230 feet above

sea, on a terrace of drift, on north slope of Ben Erival. (*Abstract*, p. 813.)

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Plate IX. No. 22. *Barra.*—Boulder on west slope of Ben More hill, on shore of Atlantic, at height of 165 feet above sea, butted by rock at its east end. (*Abstract*, p. 815.)

Plate IX. No. 23. *Loch Boisdale.*—Two boulders, A and B; A butted at its east end on rock of Kennet Hill, and B resting with its east side on A. (*Abstract*, p. 815.)

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Plate X. No. 26. *South Uist*, Jocdar; rocks extensively smoothed and striated from N.W. (*Abstract*, p. 816.)

Plate IX. No. 27. *Harris*, at Borve, on shore of Atlantic; two boulders on hill-side sloping down towards sea, the uppermost having apparently come from west. (*Abstract*, p. 817.)

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Plate X. No. 29. *The Lewis.*—Hill top at Miavig, covered by boulders chiefly on west side. (*Abstract*, p. 819.)

Plate X. No. 30. *Skye.*—Boulder on rocky ridge, between Loch Scavaig and sea, on west coast. (*Abstract*, p. 821.)

Inverness-shire.

Plate X. No. 31. *Fort-William.*—Boulder on steep western side of Treshlik Hill. Two views given; upper one shows part of hill on which boulder lies; lower one shows steepness of slope. (*Abstract*, p. 825.)

Plate X. No. 32. *Flichity Valley.*—View of an isolated hill, about 1620 feet above sea, with many boulders on west side. Two views given; that on left hand, to show shape of hill and position of the boulders; the other to show steepness of hill slope. (*Abstract*, p. 834.)

Plate X. No. 33. *Glencoe.*—Boulders of gneiss, lying at foot of cliff, which faces east; supposed by Convener to have come up valley, till obstructed in farther progress by cliff. (*Abstract*, p. 830.)

Plate X. No. 34. *Farr Parish.*—Boulders on rocks smoothed, and sloping down to westward. (*Abstract*, p. 835.)

Nairnshire.

Plate X. No. 35. *Croy.*—"Tom Rioch"—large angular Conglomerate boulder—to show shape, notwithstanding long distance carried. (*Abstract*, p. 850.)

Plate X. No. 36. *Cawdor.*—Sketch of four other large angular Conglomerate boulders given for same reason. (*Abstract*, p. 851.)

Perthshire.

Plate X. No. 37. *Callander.*—Bochastle Hill. Two gneiss boulders, lying on Conglomerate rock, which forms west part of hill. The largest ($14 \times 9 \times 9$ feet) is on very summit of hill. Its shape shown by fig. *a* in diagram; that of smaller one by fig. *b*. (*Abstract*, p. 856.)

Plate X. No. 38. *Dochart Valley.*—Rock on south side of, smoothed and rutted horizontally from west. (*Abstract*, p. 858.)

Plate X. No. 39. Boulders on ridge of hills, 2300 feet above sea, and horizontal strata broken up. (*Abstract*, p. 859.)

Ross-shire.

Plate X. No. 40. *Gairloch.*—Granite boulder 747 feet above sea, on edge of a high cliff, facing west; resting on schistose gneiss. It projects $2\frac{1}{2}$ feet beyond edge of cliff. (*Abstract*, p. 861.)

Plate X. No. 41. *Gairloch.*—Hill N.E. from Gairloch Hotel, 585 feet above sea, on summit of which there are two boulders. (*Abstract*, p. 861.)

Plate X. No. 42. Shows the largest of these boulders, projecting 2 feet beyond edge of precipice, and sloping down towards N.W. at an angle of 15°. The smaller boulder lies on a rocky surface sloping down W.N.W. (*Abstract*, p. 861.)

Plate X. No. 43. Rocky knoll, near base of above hill, with a cluster of boulders on it, showing that uppermost boulder had come from west. (*Abstract*, p. 861.)

Plate X. No. 44. *Loch Maree.*—On hill to west of hotel, a boulder near top on west slope, butted against rock at its east end. (*Abstract*, p. 862.)

APPENDIX II.

Summary of Facts contained in the Nine Annual Reports of the Committee, and of Inferences apparently deducible from these Facts, bearing on the Question, by what Agency Boulders were transported to their present Sites.

I. *Distribution of Boulders in Scotland.*

It might be possible to extract from the Reports, approximately, the *numbers* of boulders in each county, so far as made known to the Committee. But these numbers would give a very incorrect idea of either the prevalence or the paucity, originally, of the boulders in different parts of Scotland,—*first*, because counties vary extremely in size; *second*, because from some counties the information sent was more copious than from others; *third*, because in some counties, where agricultural improvements have been extensive, boulders in thousands have long ago disappeared by wholesale extirpation.

In the absence of precise statistics, it may be stated generally, that there is no Scotch county where boulders do not exist, and that on all the islands, including the Hebrides, Orkney, Shetlands, and the Faröes, boulders are found.

If, however, an opinion on this point is of any value, the Convener may say, that having visited two-thirds of the Scotch counties, to inspect and search for boulders, he considers that they are in much larger numbers on the West Coast, and the hills adjoining the West Coast, than on any other district of the same extent.

II. *Size or Weights of Boulders.*

It will be seen from the Abstract, and still more from the Annual Reports, that the dimensions of the boulders, when of considerable size, are in most cases there given. But in this Summary, it may be sufficient to refer to cases of boulders made known to the Committee exceeding 100 tons in weight.

The element of large size or weight has some bearing on the question, What could be the agency by which boulders were transported? especially if it appears that many were transported great distances, and across valleys and hill ranges, as to fulfil these conditions the transporting agent would require to be of peculiar power and magnitude.

Examples of Boulders exceeding 100 Tons in Weight.

1. *On Mainland.*

Aberdeenshire—Chapel Garioch, boulder 250 tons (*Abstract*, p. 771).
Kemnay, two boulders, 270 and 380 tons (*Abstract*, p. 771).

Argyleshire—Kilhenzie, boulder 150 tons,
Loch Goil, „ 300 „
Loch Long, „ 380 „
Loch Fyne, „ 286 „
Gareloch, „ 240 „
(*Abstract*, pp. 773, 774, 776).
Loch Awe, „ 130 „ (*Abstract*, p. 777).
„ „ 136 „ (*Abstract*, p. 778).
Loch Killesport, two boulders, 106 and 300 tons (*Abstract*, p. 778).
Loch Killesport, boulder 2770 tons (*Abstract*, p. 779).
„ „ 520 „ (*Abstract*, p. 779).
Clach Briach „ 138 „ (*Abstract*, p. 779).
Taynish, two boulders, 108 and 116 tons (*Abstract*, p. 780).
Appin, two boulders, 124 and 292 tons (*Abstract*, p. 784).
Loch Creran, two boulders, 280 and 380 tons (*Abstract*, p. 784).

Ayrshire—Loch Doune, boulder, 444 tons (*Abstract*, p. 785).
Girvan, two boulders, 100 and 180 tons (*Abstract* p. 785).
Ardrossan, boulder, 320 tons (*Abstract*, p. 785).
Culmonell, two boulders, 326 and 552 tons (*Abstract*, p. 786).

Dumbartonshire—Loch Lomond, boulder, 246 tons (*Abstract*, p. 795).

Inverness-shire—Dochart, boulder (?), 1950 tons (*Abstract*, p. 828).
Ben Nevis, „ 118 „ (*Abstract*, p. 825).
Clachnaharry, boulder, 100 „ (*Abstract*, p. 833).
S.W. of Inverness, boulder, 310 tons (*Abstract*, p. 834).
Loch Clachan, boulder, 218 tons (*Abstract*, p. 835).

Morayshire—Craig, boulder, 652 tons (*Abstract*, p. 834).
Dallanossie, boulder, 360 tons (*Abstract*, p. 834).

Perthshire—Aberfeldy, boulder, 600 tons (*Abstract*, p. 855).
Doune, „ 900 „ (*Abstract*, p. 857).
Fortingall, „ 300 „ (*Abstract*, p. 857).
Pitlochry, „ 800 „ (*Abstract*, p. 859).

Renfrewshire—Kilbarchan, boulder (?), 300 tons (*Abstract*, p. 859).

Ross-shire (West Coast)—Glenelg, boulder, 280 tons (*Abstract*, p. 860).

Stirlingshire—St Ninians, boulder, 200 tons (*Abstract*, p. 872).
Landrick, „ 360 „ (*Abstract*, p. 873).

Sutherlandshire—Golspie, „ 120 „ (*Abstract*, p. 874).

2. *On Islands.*

In Arran—boulders respectively of 212, 362, 184, and 620 tons (*Abstract*, pp. 791, 792).

Coll Island—boulder of 308 tons (*Abstract*, p. 811).

Iona—two boulders, 400 and 190 tons (*Abstract*, pp. 808, 809).

Barra—boulder of 890 tons (*Abstract*, p. 813).

South Uist, Boisdale, boulder, 146 tons (*Abstract*, p. 815).

Shetlands—(Lunnasting), two masses of rock (supposed to have been carried some distance), respectively 1466 and 670 tons (*Abstract*, p. 869).

If cases of boulders (say) above 50 tons, had been enumerated, the number would have been at least twenty times greater.

III. *Shapes of Boulders.*

Two classes may be specified—(1) angular and rough, (2) rounded and smooth, on the surface.

In all the Scotch counties, both of these classes exist;—with this distinction, that the second class are generally embedded in drift, whilst the first are mostly, at all events, now, on the *surface* of the district (*Abstract*, pp. 849, 850).

If, as may be assumed, the erratic blocks referred to in the Committee's Reports were originally fragments from rocks *in situ*, then it is probable that the most rounded are those which have undergone most "wear and tear" by transportation.

Boulders of both classes, have often a long and a short axis;—smooth boulders more frequently so, than others. The latter are also frequently "*Pear-shaped*," indicating that one end has probably undergone more friction than the opposite end. See, as an example, "*Dana* boulder," on p. 781 of *Abstract*.

In such cases it has also been observed that when one end is smooth and sharp-pointed, the opposite end is generally square or rough.

IV. *Particular Markings on Boulders.*

On some Boulders there are occasionally grooves, ruts, striæ, and scratches upon their surface when smooth.

The incisions generally form lines approximately parallel with the longer axis of the boulder. They may occur on one or more of the sides, *i.e.*, along the upper, lateral, and under surfaces.

Examples of marks on the under surface will be seen by referring to the *Abstract*, p. 769 (*Aberdeen*); p. 808 (*Iona*); p. 845 (*Tynecastle*); and p. 847 (*Alnwick Hill*).

It has been thought, that from a close examination of ruts and striæ, whether on boulders or on rocks, the direction of the striating agent can be inferred by observing at *which* end the striæ have been most deeply cut. In multitudes of cases it has been observed, that the striæ are more deeply cut at one end, whilst towards the other end they gradually thin away and disappear. In explanation of this fact, it is suggested that hard pebbles or stones, acting as incising tools, would, in advancing along

the surface of the boulder or the rock, become blunted under severe pressure, and be at length crushed to pieces.

In the Tynecastle boulder, striæ were seen on both the upper and the under surface. Those on the upper surface showed incision from a *westerly* point; those on the under surface, showed incision from an *easterly* point, judging by the test before referred to. If the boulder had been pushed over sharp rocks from the westward, the ruts on the lower surface would, according to that test, show that they had begun to be formed at the *east* end. After the boulder had become fixed in position, a drift of hard shingle passing over the top from the west would produce striæ beginning at the *west* end.

It is evident that striæ could be formed less easily on the vertical or lateral sides of a boulder than on the upper or under sides, as the incising pebbles might not, in the first case, so easily continue to move in a horizontal direction. One boulder is mentioned where striæ were seen on both sides of the boulder—these sides meeting at, and radiating from, a point at one end, as shown in the woodcut on p. 802 of *Abstract*. The case is interesting on account of its bearing on the agency which produced the striæ, as it must have been such as to be capable of being separated into two currents when it reached the boulder, in which case a current would flow along each side, pushing and pressing drift on the surface of the boulder as it passed.

It is proper also to notice, as bearing on the same question, that boulders sometimes show two sets of striæ, the one set crossing the other obliquely, indicating a change in the direction of the striating agent, or else in the position of the boulder. The case, for example, on page 844 of *Abstract*, shows one set of striæ running N.N.W., and the other W. by S. (Easter Duddingstone).

As the study of striations may throw light on the nature of the transporting agent, it is right to take notice of striations on solid rocks; for if there are on *them* two sets of striations crossing one another, the cause must be ascribed either to a change of direction in the movement of the striating agent, or to the advent of another striating agent from a different quarter.

Examples of two sets of *striæ* on a rock surface will be seen in *Abstract*, p. 839 (*Glasgow*) and p. 849 (*Carden Hill*).

That the striations on rocks were produced by an agent, the same as, or similar to, that which caused striation on boulders, is evident from the multitudes of cases where there are striated boulders and striated rocks close to or near one another, the direction and appearance of the striæ on both being generally the same.

Great numbers of rock striations occur in the Hebrides, most of which are described in the *Fifth Report.* Thus (at p. 816) an account is given of smoothed rocks at Jocdar, on which there are twelve or fourteen deep ruts, some of them 4 or 5 feet in length. One measures 8 inches across and 2 inches in depth, and there are others of similar width and depth,—the ruts being in all cases deeper and wider at their west than at their east ends. In the *Lewis*, at *Uig* and *Carlowrie* (*Abstract*, p. 819), similar cases occur; also *Kilmory* (*Abstract*, p. 780), *Buteshire* (*Abstract*, p. 791).

These rock striations are found not only on surfaces more or less horizontal, but also on surfaces which *slope*, and even on surfaces which are *vertical.*

As examples take the two following cases :—

1. In *Bute*, there is a rocky defile, about 30 yards wide, at *Barone Hill* (*Abstract*, p. 793), through which boulders and drift materials have evidently passed. One side of this defile presents extensive smoothings, on which there are ruts, some of them 12 feet in length, and more deeply cut into the rock, at the end where the striating agent entered the gorge, viz., the N.W. The direction of movement is farther shown by the fact, that from that end the ruts slope *upwards* at angles of from 20° to 30°, the result, no doubt, of the force with which the materials were pushed or driven through the gorge (*Seventh Report*, p. 19).

2. Another example occurs on the west side of *Arthur's Seat*, Edinburgh, as explained in *Abstract*, p. 843. Boulders and other drift materials had passed through this gorge, which is only about 10 yards wide. A boulder sticking on one of the sides was striated on its exposed side. One of the rocky sides also presented numerous striations,—some of them 6 feet in length, and $\frac{1}{3}$ of an inch deep. At the narrowest part of the defile, where there would be the greatest difficulty in forcing a passage, the striæ are rising up at an angle of 4° or 5° from the end where the materials had entered the defile.

V. *Particular Positions of Boulders.*

Explained under the following heads:—

1. In beds of clay, gravel, and sand.
2. On the surface of the country.
   - *a.* Lying on flattest side.
   - *b.* Standing on end.
   - *c.* Butted against rocks or resting on other boulders.
   - *d.* Resting on steep slopes of hills.
   - *e.* Resting on ridges and tops of very high hills.

1. *Embedded in Clay, Gravel, or Sand.*

In *Aberdeenshire* a boulder of 8 tons found in a bed of sand (*Abstract*, p. 769).

In *Ayrshire*, large boulders found in a bed of sandy mud at a depth of 18 feet, the boulders being covered with *Balani* and *Serpulæ* (*Abstract*, p. 786 (3)).

In *Renfrewshire*, near Paisley, boulders in clay beds, found with *Balani*, which had grown on them (*Abstract*, p. 860).

On an island in *Loch Lomond*, a bed of boulder clay occurs containing Arctic shells.

In *Arran*, beds of boulder clay occur, with blocks and broken shells (*Abstract*, p. 793.)

In *Aberdeenshire*, thick masses of unstratified pebbly mud occur, with stones and Arctic shells, most of them broken, but some entire (*Abstract*, p. 772).

In the *Lewis*, at several places, boulder clay occurs, with boulders and fragments of sea-shells (*Abstract*, p. 821).

In *Caithness*, at Keiss, Wick Bay, and Scrabster, there are beds of boulder clay and drift, containing shells and stones, some of which are scratched; one boulder in the Wick clay bed is 12 feet in length (*Abstract*, p. 794).

In the *Orkneys*, the islands of Eda, Sanday, Stromsa, Shapinshay, and Ronaldshay present clay beds containing boulders foreign to the islands, and marine shells, most of them broken or striated, as well as the boulders (*Abstract*, p. 853).

The cases of boulders, with *Balani* and *Serpulæ* found on them, have been explained by supposing that after these fish had grown on them the boulders were lifted by floating ice and dropped elsewhere (*Abstract*, pp. 786 and 860).

2. *Boulders on Surface of the Country.*

(*a*) *Boulders lying on flattest side* occur so frequently that it is not necessary to quote cases.

(*b*) *A less frequent case is when boulders occur standing on end.*

This observed occasionally, when boulders embedded in clay or sandy mud (see *Estuary of Forth*, p. 99, and *Ed. Roy. Soc. Trans.*, vol. xxvii. p. 630, and *Ramsay's Physical Geology*, p. 155).

Also observed on open surface of the country; when the boulder leans against a rock, as at Iona, in the case of the large boulder at Dun I;—and of a small boulder near south end of island (*Abstract*, p. 808).

(*c*) *Butted against rocks, or resting on or against other boulders.* See such cases mentioned (*Abstract* pp. 773, 780, 793, 808, 810, 812, 818, 836, 861, 862).

(*d*) *On steep sides of hills.*

In *Abstract*, p. 825, there is notice of an isolated hill (Treshlik Hill), on an exceedingly steep side of which a large boulder rests (*Lithograph* No. 31, Plate X.).

In *Abstract*, p. 834, there is notice of another isolated hill in Flichity valley, on which there are several boulders precariously situated, because of the steepness of the hill-side (*Lithograph* No. 32, Plate X.).

In *Abstract*, p. 824, a remark by Professor Duns is referred to, with regard to some granite boulders lying on a part of Ben Nevis, where the mountain slopes down so steeply, "as to make it a puzzle to understand how they can remain in position."

In *Abstract*, p. 856, see similar cases, on Bochastle Hill and Clunie.

In *Abstract*, p. 862, notice will be found of a large boulder resting on a slope at an angle of so much as 47°.

(*e*) *On tops of hills.*

In *Aberdeenshire* (*Ballater*), boulders of granite and gneiss are on the summit of a hill, at height of 2963 feet; there being no rocks of that nature *in situ* on the hill (*Abstract*, p. 770).

In *Aberdeenshire* (*Braemar*) there are boulders on tops of hills

reaching 2700 feet and 3587 feet above the sea (*Abstract*, pp. 770 and 771).

In *Inverness-shire*, at the heights of 2000, 3000, and 3155 feet, Lochaber (*Abstract*, pp. 824, 826, and 827);—of 3425, Albannach (*Abstract*, pp. 828, 829); 3407, Schehallion (*Abstract* p. 830).

In island of *Mull*, a boulder on the top of *Spyon More*, at a height of 2435 feet above sea (*Abstract*, p. 808).

In *Kirkcudbrightshire*, at a height of 2764 on summit of Merrick (*Abstract*, p. 837).

In *Glencoe* district, boulders found on summits and peaks of *Aonach* and *Eagach*, and *Meal Dearg*, at height of 3110 feet above sea. Professor Heddle remarks that "these boulders lay on a ridge not many times wider than their own bulk," and "occupy positions *much higher in level than any of the hills in a very wide extent of country*, so that it is difficult, if not impossible, to adopt for them the explanation of any local glacier" (*Abstract*, p. 830).

The following are cases where boulders are on tops of hills of less height above the sea than in the cases just mentioned; but, being higher than any other hills in the district, they present a feature similar to that just noticed by Professor Heddle. As examples of these, reference is made to boulders on *East Loch Tarbert* (*Abstract*, p. 775); *Inverary* and *Loch Awe* (*Abstract*, p. 777); *Islay Island* (*Arnahoo*) (*Abstract*, p. 806); *Forfarshire* (*Abstract*, p. 801); *Lochaber* (*Abstract*, p. 825); *Kirkcudbright* (*Abstract*, p. 837); *Midlothian* (*Abstract*, p. 840); and in *Sutherlandshire* (*Abstract*, p. 875). Similar cases of boulders perched on very precarious positions probably occur in Skye, judging by what is said of them by Macculloch and Forbes (*Abstract*, p. 822).

VI. *Cases where Parent Rocks of Boulders have almost certainly been ascertained.*

1. In *Berwickshire*, granite, sienite, porphyry, and whinstone boulders are clearly traceable to hills situated several miles to the westward (*Abstract*, pp. 787, 788, 789, 790).

2. In *Roxburghshire* there are similar cases (*Abstract*, p. 865), in some instances the parent rocks being at least 20 miles to the westward.

3. In *Peeblesshire*, a quartz boulder, with much probability referred to beds of quartz about 80 miles to the westward (*Abstract*, p. 855).

4. In *Haddingtonshire, Isle of May*, and *Inchkeith* there are granite boulders which must have been carried at least 100 miles from westward (*Abstract*, pp. 801 and 802).

5. In *Midlothian* there are numerous cases of granite and other boulders, which must have been carried 50 to 80 miles from westward (*Abstract*, pp. 840, 844, and 847).

6. In *Linlithgowshire* cases are mentioned of whinstone and Conglomerate boulders carried from westward (*Abstract*, pp. 839, 840).

7. In *Aberdeenshire*, granite blocks from hills situated many miles distant to N. and N.W. (*Abstract*, p. 769 and 770).

8. In *Forfarshire*, mica schist boulder from rocks 17 miles to W.N.W. (*Abstract*, p. 801).

9. *Inverness-shire*, granite boulders at and near Loch Tulla traced to hill 10 miles to westward, also near Inverness (*Abstract*, pp. 828, 832, and 833).

10. In *Argyleshire* (Kerrera, Easdale, and Lismore), granite boulders, referred to sources situated to the north, across the sea (*Abstract*, p. 783).

11. In the *Lewis*, granite boulders from Barvas Hills, situated to N.W. (*Abstract*, 820).

12. In *Perthshire*, a Conglomerate boulder, weighing 900 tons, carried about 7 miles from westward (*Abstract*, p. 857).

13. In *Stirlingshire*, numerous cases of Conglomerate boulders in different localities, carried from 10 to 20 miles from westward (*Abstract*, p. 873).

14. In *Glencoe*, boulders which must have come down valley, viz., from S.E. (*Abstract*, p. 830).

15. In *Morayshire, Nairn, Elgin*, and *Ross-shire*, boulders of Conglomerate, and various kinds of granite, which have travelled 10 to 30 miles from westward (*Abstract*, pp. 798, 848, 851, and 852).

16. In *Buteshire* (*Cumbraes*), boulders of Conglomerate from N.W. (*Abstract*, p. 791).

17. In *Kirkcudbrightshire*, Criffel granite boulders carried S.E. even to Cumberland and Lancashire (*Abstract*, pp. 796, 797, and 838).

VII. *Special Facts indicating direction in which Transporting Agent moved.*

1. *Longer axis* of boulders and sharp ends of boulders generally point north-westward.

The cases showing this, which are mentioned in the Reports and Abstract, are so numerous that they need not be particularised.

Testimony to the north-westerly direction from which boulders in Scotland have been carried, is given by the following geological authorities—Professor Geikie (*Abstract*, p. 841); Sir Roderick Murchison (*Abstract*, p. 795); Charles Maclaren (*Abstract*, p. 840); Robert Chambers (*Abstract*, p. 876); J. F. Campbell (*Abstract*, p. 815); J. F. Jamieson (*Abstract*, p. 795); Professor Harkness (*Abstract*, p. 797); W. Jolly (*Abstract*, p. 799); Mr Anderson Smith (*Abstract*, p. 776); John Young (Glasgow University) (*Abstract*, p. 839); James Croll (*Abstract*, p. 841); T. Hay Cunningham (*Abstract*, p. 838).

In the *Lewis* there are kaims or escars on a very large scale,—continuous for several miles, whose north-westerly direction, and numbers of boulders lying upon them, suggest the idea that they may be due to the same agency which has transported the boulders (*Abstract*, p. 820).

2. But whilst a movement from north-westward is very general in Scotland, it is right to notice exceptional cases.

In *Loch Long* and *Loch Fyne* there has been a movement from N. or N. by E. (*Abstract*, p. 774, 775). In *Islay* (*Abstract*, p. 806). *Buteshire* (*Abstract*, p. 791).

In *Morayshire* and *Elgin* Mr Jolly points out two streams, one from 6° S. of west,—the other from 15° N. of west (*Abstract*, p. 799).

In *Perthshire* (*Dunkeld*) the direction of the striæ on the rocks at a high level is from N.N.W.,—whilst at a lower level, in the same valley, it is from N.E. (*Abstract*, p. 857). In the *Lewis* a similar case occurs;—the direction of the movement at a high level being from W.N.W.; and at a low level, in the same district, from W., or even W.S.W. (*Abstract*, p. 819). In *Assynt*, whilst the normal direction is N. 60° W., the direction changes to due north, caused (as Chambers supposes) by the interference of a hill (*Abstract*, p. 875).

So also near Gairloch, whilst the normal movement is from W.N.W., as shown by boulders and striæ, there is a locality among the hills, where the movement is shown to have been from W.S.W. (*Abstract*, p. 861).

Cases have already been noticed, where there are two sets of striæ crossing one another. Thus in Morayshire (*Abstract*, p. 849) the N.W. striæ are crossed by others of a later date coming from N. by E.

Near *Glasgow* there are rock surfaces presenting two sets of striæ, one implying a movement from the N.W. and N.E. respectively (*Abstract*, p. 838).

These different directions in the lines of striæ may, in some cases, indicate two separate agencies, moving independently of one another at different periods. But it is also possible that the same agent might be deflected from its normal direction by local conditions. An example of such a deflection is given by Sir James Hall, in his well-known paper on "Revolutions on the Earth's Surface" read by him in the year 1812, and printed in the 7th vol. of the *Ed. Roy. Soc. Trans.* He names a locality (p. 196), where "the rock presents furrows and scratches similar to those on Corstorphine Hill,"—but where "the action of the stream has undergone a *visible modification*, by the prominent form of some parts of the rock, in consequence of which the dressings have in some places been *turned* to the amount of 5° or 6° *out of the general direction*, which, however, they resume gradually in the course of a few yards."

In Haddingtonshire, whilst the normal direction is generally from W.N.W. on *horizontal* rock surfaces, the movement slightly changes where the striating agent struck upon, and had to pass over, a rock which *sloped.* For example, at *Linton*, on a rock surface sloping down due north, at an angle of 35°, the direction on that surface is E. and W. (*Abstract*, p. 803).

At the *railway cutting*, not far from Linton, the rock surface slopes down due north, at an angle of 10° to 20°; and the opposing rock surface being here of considerable extent, the direction of the striæ is E. 15° N. (*Abstract*, p. 803).

On *North Berwick Law* the smoothed rock surface dips down N. 10° W., and the direction of the striæ is E. 22° N. (*Abstract*, p. 805).

3. Another set of facts, bearing on the direction in which the transporting agent has moved, is the position of individual boulders.

A very large proportion of boulders have been lodged on the *west* slopes of hills. Many are butted up against rocks, or lying on other boulders, in a way which shows that they came from the *westward.*

4. Another fact has been observed, which shows that there has been a general movement over this part of Europe from a westerly point.

Thus in describing the beds of boulder clay in the neighbourhood

of Edinburgh, the Rev. Dr Fleming cites different localities where it clearly appears that the materials composing the boulder clay, had been by some extraneous agency pushed *towards the east;* and pushed so violently, that the strata of rock covered by the boulder clay had their *edges broken off*, and carried towards the east (*Lithology of Edinburgh*, pp. 52 to 60).

In like manner, Professor Geikie says that "the mass of the boulder clay (in the basin of the Firth of Forth for instance) consists of the comminuted debris of the Carboniferous and other rocks which form the framework of the district. We can also gather that this loose fragmentary matter has *moved* from *west* to *east.* In the upper part of the basin of the Firth of Forth the coal fields are covered with *red* boulder clay, *abounding in fragments of the rocks* that lie towards the N.W., and deriving its prevalent tint from the waste of the Old Red Sandstones, and stretches up to the foot of the Highland mountains" (*Glacial drift*, p. 805).

5. If the foregoing data are sufficient to establish the general fact that the transporting and striating agent has moved in most parts of Scotland from the north-westward, the question arises, What was that agent?

In regard to boulders in Forfarshire and Aberdeenshire, it might be inferred that *they* were brought by glaciers from the Grampians and other mountainous districts there. But some of these boulders are at such heights as to suggest doubts whether any glacier could have been generated at such a level as to bring these boulders. Moreover, several of the Forfarshire boulders, if they came from the mountains to the west, must have crossed valleys and ridges of hills, which would have seriously obstructed the flow of a glacier (*Abstract*, p. 801).

In some districts, however, there is undoubtedly evidence to establish glacier action;—as in *Glencoe* (*Abstract*, p. 830). Professor Heddle and Mr Livingstone satisfied themselves of the existence of one or more glaciers on the west flanks of *Ben Nevis*, though Mr Livingstone sees difficulties which he cannot explain (*Abstract*, p. 824). Professor Duns seems also to recognise the probability of a Ben Nevis glacier (*Abstract*, p. 824). In *Nairn Valley* there are also appearances which suggest the agency of a local glacier (*Abstract*, p. 835). *Loch Skene* is another case (*Abstract*, p. 796).

In *Glen Etive* and *Loch Etive* there are indubitable traces of glacial action at a low level, moving from Loch Awe (*Abstract*, p. 782).

But in *Inverness-shire* there are boulders, reported on by Professor Heddle, which, as they must have crossed deep valleys, floating ice must be preferred for agency of transport in these cases (*Abstract*, p. 829). See also *Ruberslaw* (*Abstract*, p. 866); *Shetland* (*Abstract*, p. 869). *Forfarshire* (*Abstract*, p. 801). *Sutherland* (*Abstract*, p. 875).

That at the Boulder period floating ice of some kind existed can scarcely be doubted.

The confident testimony of Dr Chambers, Professor Nicol, and Mr Jamieson, that the positions of the boulders and the direction of the rock striations on the north-west coast are inexplicable, except on the supposition that the transporting and striating agent came there *from the sea*, scarcely leaves room for doubt (*Abstract*, p. 795).

The transport of boulders from the westward is especially interesting in those localities on the north and north-west of Scotland, where towards the west there is nothing but open sea.

Thus, on the islands of Tiree and Coll, and at Borve on the west coast of Harris, the boulders are in such positions, that to reach these positions *they must* have come across the sea.

In the Shetlands and Orkneys there are on almost every island boulders which, differing in mineral constituents from the rocks of the island, *must* have been transported *across some portion of sea;* and accordingly Messrs Peach and Horne, who have lately explored the geology and the glacial phenomena of the islands, give a decided opinion that on these islands *land glaciers* were not the transporting agent. They say that in the Orkneys "the islands must have been *overflowed* by ice;"—ice which "originated beyond the limits of Orkney" (*Abstract*, p. 855). So also of Shetland, they say that "it must have been at *one time smothered in ice*"—"originating far beyond the sphere of Shetland" (*Abstract*, p. 871).

With regard to the direction of the movement of the transporting agent in Shetland and the Orkneys, there is not the same uniformity as on the mainland of Scotland. In the island of North Unst, the northernmost island of Shetland, the direction is

from W.N.W. (*Abstract*, p. 870). On the island of Papa Stour there are blocks which apparently came across St Magnus Bay from a N.E. direction (*Abstract*, p. 867). But in other cases the boulders on the islands must have been floated from many different directions.

It is also proper to notice the fact, that in some of the islands of the Hebrides, and even on portions of the west coast of the Mainland, the positions of the boulders indicate a movement, not from W.N.W. (the normal direction for Scotland generally), but from N. or N. by E., as in Islay (*Abstract*, p. 806), in Iona (*Abstract*, p. 808). Loch Fyne (*Abstract*, p. 777); Kintyre (*Abstract*, p. 773). *Buteshire* (*Abstract*, p 791).

But these exceptions do not greatly detract from the value of the generally concurring evidence, everywhere else, of a direction from W.N.W.

It is also an important circumstance that the part of Scotland where the boulders are largest, heaviest, and most numerous, is along the west coast (see p. 886). If floating ice brought boulders across the Atlantic, the first place where boulders would be discharged would be where the sea bottom rose high enough to interrupt the progress of the ice. The ice carrying the largest and heaviest boulders would most probably strike the sea bottom soonest; whilst the ice carrying smaller cargoes would flow on, till these reached the submarine rocks which now form the present inland mountains.

As bearing on the question, whether land ice or sea ice was the transporting agent, another circumstance brought out in the Reports must be kept in view. Some boulders on the tops and ridges of mountains are at heights far above what could be reached by a glacier having its birthplace in any adjoining district. Such are the boulders at heights exceeding 3000 feet; and even when at lower heights, it would be necessary, for upholding the glacier theory, to have mountains pointed out where glaciers could have been formed, and with a valley through which the glacier could have flowed in the direction of the boulder. But even if this difficulty of levels could be overcome, there is still another in explaining how a glacier could set down on the very tops of hills, or on excessively steep slopes of hills, boulders which are frequently seen in these critical positions.

Floating ice stranding on mountain tops or slopes, might, by

gradually melting, allow boulders to obtain these singular lodgments.

Of course, if the theory of floating ice be adopted, the position of boulders at heights of 3000 feet implies a sea which must have stood at that height, or more, above the present sea-level in Britain. In that supposition there is no improbability. Moreover, beds of sand, mud, and gravel (proofs of marine conditions) actually exist in several parts of Perthshire, up to a level of 1500 feet, 1600 feet, 2000 feet and more (*Abstract*, pp. 857, 858); on Ben Cruachan, up to 2000 feet (*Abstract*, p. 783); in Glencoe, up to 2000 feet (*Abstract*, p. 830); and on Schehallion, at a height of 3000 feet (*Abstract*, p. 858). The Ordnance surveyors reported drift beds at a height of even 3800 feet (*Abstract*, p. 831, footnote). Terraces on gravel andsand at 1200 feet (*Abstract*, p. 832).

In Scotland, sea-shells—and generally of an Arctic type—have been found in clay or gravel beds up to a height of about 520 feet above sea-level. In several parts of the west of England these shells occur in similar deposits up to a height of about 1200 feet, and in Ireland (near Dublin) up to a height of 1400 feet above sea-level. At the time when the sea stood at either of these heights in England and Ireland, it could not with any probability have been lower in Scotland.

Allusion has been made to deflections in the direction of the transporting agent, when it struck upon rocks, which slope towards certain points, and at different angles. These deflections can be understood and accounted for on the supposition of an oceanic current with floating ice. For by flowing over a rock, which obstructed its normal progress, the current might be deflected from its usual course. These deflections it would not be easy to explain on the theory of solid land ice moving over the country.

Another circumstance favouring the theory of an oceanic current, with floating ice, to account for the movement of boulders, and the striation of both boulders and rocks, is the presence of *marine shells*, of Arctic types, in beds of drift containing boulders. In most of the cases referred to some of the shells have been crushed, whilst others are entire and unhurt. What more probable explanation can be given of these facts, than that masses of ice floating on a sea current would, on touching the sea bottom, discharge

their cargoes of rocks and rubbish, and at the same time plough through the sea bottom, pushing forward boulders, and crushing shell fish? (See p. 891.)

It is a fact confirmatory of this view, that beds of boulder clay never show stratification, and that, moreover, in respect of colour and materials, they closely resemble hardened or compressed mud, apparently composed of the debris of rocks which had undergone disruption and friction by some extraneous agent. Boulder clay is found everywhere in Scotland,—so that there must have been one general agent instrumental in forming the deposit; and it is difficult to conceive a more probable agent than sea currents, with floating ice, grinding and grating over submarine rocks.

Another circumstance (shown in the Committee's Reports) indicates oceanic agency, viz., the uniformity all over Scotland of the direction of the striæ on rocks and boulders, and of the direction of the longer axis of boulders. In almost every part of Scotland there has manifestly been some agent of immense power, which has been for a long period passing over from the W.N.W. What other agent would produce these concurrent effects over a considerable portion of the earth's surface than a great oceanic current?

No such effects are likely to have been produced by an ice-sheet however gigantic, or still less by local glaciers.

The deflections from that normal direction, which are mentioned in the Reports as occurring in some localities, are not only not inconsistent with the theory of an oceanic current, but are just what might be expected, inasmuch as when currents flow over a bed which contains obstructions, eddies and deflections are produced, so that these partial deviations from the normal direction strengthen rather than weaken the theory of a great sea current.

There are also two districts crossing Scotland where the movement has been, by some special cause, deflected from the normal N.W. direction. In the low-level district between the Firths of Clyde and Forth, where the highest point is about 150 feet above the sea, the direction is about due E. and W. (*Abstract*, pp. 847 and 872). So also in the valley crossing the south of Scotland, the east part of which is occupied by the River Tweed and its tributaries, and the west part by the Rivers Liddell and Esk, the direction as shown by boulders, and by striations on rocks, is from W.S.W. in the western

districts (*Abstract*, p. 865), and N. 10° W. (*Abstract*, p. 790) in the eastern districts.

These deflections from the normal direction, both on the west coast and in the two districts across Scotland just referred to, can be explained on the theory of a N.W. oceanic current. The current, on reaching what are now the high mountains of Argyleshire, might be deflected there into a more southern direction; and when the current reached the two valleys referred to, it might be drawn through them by the absence in them of any obstruction.

That some oceanic current has passed through the southern valley seems evident from the numbers and direction of the kaims in Roxburghshire and Berwickshire (*Abstract*, pp. 865 and 790).

The Convener (in a paper in the *Edin. Roy. Soc. Trans.*, vol. xxvii. p. 44) ascribed the formation of these kaims to *oceanic action* through a submarine channel, formed by a range of hills on each side; and in support of his view he referred to the following passage in Professor Geikie's work on the *Great Ice Age* (p. 248), where he observes, that "when we note that strings of gravel ridges and mounds may sometimes be followed up one valley, across the dividing col, into a totally different drainage system, we cannot but conclude that ordinary river action is out of the question as an explanation of the phenomena. In the present state of our knowledge we appear to have no alternative but in such cases to admit *the marine origin of such kaims.*"

These Berwickshire and Roxburghshire kaims present features similar to the kaims of the *Lewis* (*Abstract*, p. 819), except that the agent which formed them moved in a different direction, owing to the difference of the conditions which influenced the current in the respective localities.

6. A question may be asked, that if there existed both local glaciers and floating ice, as agencies for the transport of boulders and the striation of rocks, which of these agencies was first in operation?

The data are too scanty to allow of this question being answered with any confidence.

In the *Abstract*, p. 831, where reference is made to *Glencoe*, and in *Abstract*, p. 835, where reference is made to *Farr*, it will be seen that an opinion is offered that glaciers existed *first*, and that submergence of the country took place *afterwards*.

7. It remains to notice what light is thrown on the subject by the Faröe Islands.

As Professor Geikie is satisfied that glaciers, or an ice sheet of some kind, existed, capable of glaciating the rocks and moving boulders, that view, entertained by an observer of so much experience and intelligence, will be at once accepted.

But the farther question arises, Whether there is evidence of there having existed *also*, at some other period, the agency of floating ice?

Professor Geikie does not admit that there is such evidence; and it has to be confessed that only one place on the islands has as yet been pointed out where such evidence is alleged to exist.

Mr Allan having drawn attention to the peninsula of Eide, as presenting rock smoothings and striations similar to those pointed out by Sir James Hall on Corstorphine Hill, Dr Robert Chambers, when he visited the Faröes forty years afterwards, went to Eide, on purpose (as he says) to study the appearances which Mr Allan had only generally described. He states that he "looked narrowly for the striæ or scratches;" and saw that "they presented themselves in abundance in several places;" and he says that he was satisfied that they were "all directed from the north."

Professor Geikie, in his *Memoir*, adverting to these same rocks, states, they are "perhaps the best preserved *roches moutonnées* he anywhere observed;"—but as to the direction in which the smoothing and striating agent had moved, which Dr Chambers alleged to be "from the north," Professor Geikie states that the striæ "had clearly been graved by ice, coming from *quite the opposite point of the compass*" (p. 246).

The Professor follows up this statement by explaining (p. 261) that "the long sound that separates Österöe from Stromöe (must have) brimmed with ice, which flowed in two directions; north of Nordskaale *the movement was northerly*, while south of the shallow part of that sound the ice held on a southerly course."

It is unfortunate that thus Professor Geikie and Dr Chambers, both of them competent and experienced observers, should have given opposite testimonies in this matter.

The question at issue being, as Professor Geikie states, one of

"considerable interest," it may be allowable to inquire whether any circumstances exist calculated to throw light upon it.

The glaciation and striæ on the rocks at Eide were by Dr Chambers ascribed to agency which came "from the north," viz., sea-ice. By Professor Geikie these were ascribed to the agency of land-ice, filling what is now the sound of Nordskaale, of which land-ice, one portion flowed north towards *Eide*, and the other portion held on a southerly course, each thus flowing in opposite directions from what had once been a *col*, or head of two separate valleys.

(1) There is one circumstance which seems to favour the view taken by Chambers, viz., that Mr Allan, when he examined the rocks, evidently considered that the agent which produced the markings, was the sea. He adopted for an explanation of these, Sir James Hall's opinion, suggested by the similar phenomena on Corstorphine Hill, viz., diluvial agency. The smoothed and striated rocks on the sea-coast at Eide forming a "headland," as Mr Allan called it, would no doubt seem to him well suited to illustrate such an agency. He accordingly takes notice of these rocks as "scooped and scratched in a very wonderful degree, not only on the horizontal surface, but also on a vertical one, of 30 to 40 feet high, *which had been opposed to the current*, and presented the same scooping and polished appearance with the rest of the rocks, both *above* and *below*."

If this be a correct view of Mr Allan's opinion, he is so far a witness corroborative of Chambers.

(2) Another circumstance bearing on the question, is the apparent difficulty of any glacier being formed which could reach the rocks at Eide, glaciated as they are, up to a height of 1302 feet (*Abstract*, p. 879).

The distance of Eide from the col (from which Professor Geikie supposes the glacier to have flowed in its northward course) is between 8 and 9 miles. At the *col* (as the map shows) the valley is exceedingly narrow, and the hills on each side apparently are not so high or so shaped as to afford good gathering ground for a large accumulation of ice. The hills there do not seem to be above 2000 feet high. Supposing ice to have filled the valley there even up to that height, and to flow towards the north, would it ever reach Eide?

There are two difficulties in the way. *First*, the map shows that between the *Col* and *Eide* the valley widens immensely, so that the glacier would almost certainly stop and break up at that place where there is both breadth and depth. *Second*, there is no *gradient* along the bottom of the valley from the *Col* to *Eide* to draw down a glacier, because, as Professor Geikie explains, the depth of water in the sound at *Eide* is much less than at places between *Eide* and the *Col* (*Abstract*, p. 880).

In these circumstances, there seems more probability that at this place the striations and smoothings were made by sea-ice than by a glacier.

(3) The mouth of the fiord is open towards the north, and when the Faröes were 1600 or 2000 feet submerged, there would be ample opportunity for floating ice to pass through the sound.

This view is to a certain extent supported by the curious circumstance, that in many parts of the Faröes the hills are glaciated everywhere *below* a pretty uniform level of 1600 feet, whilst *above* that level most of them are rough. In that northern latitude, if land-ice prevailed generally, so as to produce an ice-sheet or local glaciers, one does not see why the hills should not have been covered and glaciated to their tops.

Moreover, if it is established that to the W. and N.W. of the mainland of Scotland floating ice was brought by some north-west oceanic current, the fact that the Faröes are 2° farther north in latitude would bring them the more readily within reach of such a current.

8. The conclusion to which the facts set forth in this summary lead is, that if boulders were brought to this country by a great north-westerly oceanic current, some of these boulders now on our hills may, in mineralogical composition, be found to differ from British rocks; and in that view, it is only right to notice, that two geologists, having considerable personal knowledge of British rocks, state that boulders have been seen by them in this country, differing in mineral composition from any rocks in Great Britain with which they were acquainted. One of these authorities is the late Professor Nicol of Aberdeen University (*Abstract*, p. 841). The other is Mr James Plant of Leicester, to whom the English Boulder

Committee, in their *Second Report* (for 1874, p. 197), refer in these terms :—

Mr James Plant reports both "isolated boulders and groups of boulders, and he records one remarkable fact of especial importance, viz., that a group of boulders had been exposed in an excavation made in Leicester, 25 feet deep, composed of rocks, which Mr Plant failed to recognise as British."

If this testimony be verified, the fact would be *in pari cases* with the case of the three plants * found in the Hebrides and the west coast of Ireland, but unknown in any other part of Europe, whose native habitat is Boreal America, and whose transportation to our shores the late Professor Edward Forbes did not hesitate to ascribe to floating ice (*Memoirs of the Geological Survey of Great Britain*, vol. i.).

Finally, it may be asked, if the theory of an oceanic current with floating ice be adopted to account for most of the boulders in Scotland, especially those on the west and north-west coasts,—from what country could the boulders have come, and what could have produced this current?

The Committee, though not acknowledging the impossibility of suggesting an answer to this question, think that were they to venture on doing so, they would be trespassing beyond the objects of their appointment. Their proper province has been simply to collect facts bearing on boulders in Scotland, embracing their distribution, their positions, and the agencies probably concerned in their transport. To explain the source or origin of these agencies, or, in other words, to unravel the conditions of the earth's previous history, so as to account for these agencies, is a problem the solution of which must be left to others.

* The names of these plants are *Eriocaulon septangulare*, *Neottia gemmipare*, and *Sisyrinchium anceps*.

5. Remarks by Mr Milne Home on presenting Tenth Report of Boulder Committee, 21st July 1884.

In presenting this the Tenth and Final Report of the Society's Boulder Committee, I hope to be allowed to offer some explanations bearing on the work which the Committee has been able to accomplish.

The chief object for which the Committee was appointed, being to obtain from Scotland, generally, as much information as possible regarding boulders, the Committee could think of no better plan of commencing work, than by addressing circulars, first to the clergyman, and next to the schoolmaster in every rural parish (including the Hebrides, Orkney, and Shetland), asking whether any boulders of large size existed in these parishes?—and if so, inviting information regarding such boulders, on points which it was expected might without much difficulty be understood and answered by the parties addressed.

The Committee were gratified by the readiness with which these appeals were responded to; and I now, in name of the Committee, or rather, may I venture to say, in name of the Royal Society, beg to express our thanks for the courtesy shown to us by those who sent answers.

Independently of information about boulders contained in the answers to our Circulars, the Committee discovered from many of these answers, the names and addresses of persons in different parts of the country, who, we were told, took an interest in the objects of the Committee, and who were even so obliging as to allow it to be mentioned to us, that they would be happy to show the boulders in their neighbourhood to any members of the Committee. These offers came not only from clergymen and schoolmasters, but from resident landed proprietors and others, who through the clergy and the schoolmasters in their several parishes happened to hear of the

inquiries which our Society had set on foot; and now, by way of acknowledging the services, and in some cases also the hospitality rendered by the persons to whom I refer, I propose to leave in the hands of our Secretary the names and addresses of these persons, not doubting that, if any one desires to obtain further information regarding boulders situated at or near the places where they reside, they would, if applied to, be still willing to aid in the inquiry.

At the close of the Committee's Report, there is in Appendix II. a memorandum, called a Summary of Facts, and of inferences from the facts, bearing on the question, What was the nature of the agency by which boulders were brought to their present sites?

This being the critical question, for the elucidation and discussion of which the Committee was expected to gather data, it would have been desirable had the Committee, as a united body, pronounced findings in which the members could all concur. I knew, however, that it was hardly possible to expect this; and I saw that the best course would be for me, as Convener, to undertake the duty of framing a memorandum, and submitting it to the Committee for insertion in the Report, as an Appendix, on the understanding, however, that no one but myself should be committed to the views contained in it. This course was approved of by the Committee. But I felt my own responsibility in this matter so much, that at our last Committee meeting, I earnestly urged one of my colleagues, who I believed was eminently competent, to draw out a memorandum of his own views, independently and irrespective of mine. I regret to say, that on the ground of his not thinking himself able for the duty, he too modestly declined it; though from what I knew, and what the Council knows of this gentleman's qualifications, I feel sure that any memorandum from him would have added greatly to the value of this Report.

I may now state in a few sentences the conclusions to which, as Convener, I have come in this inquiry, after giving mature consideration to the investigations of the Committee. These are—

1. That at some period, geologically recent in the earth's history, an Arctic climate prevailed in this part of Northern Europe, which had the effect of producing local glaciers in Scotland; of some of which glaciers there are traces still visible in the most mountainous of our districts, as pointed out in our last Report.

2. That subsequently Scotland was for a considerable time submerged beneath the sea, which over-topped our highest mountains, covering *them*, and filling most of our *valleys* with sand, gravel, and mud, beds of which are noticed in our Reports as still visible, up to a height of at least 3000 feet above the present sea-level,—thereby concealing to a great extent, traces of the previous local land glaciation.

3. That whilst Scotland was so submerged, and probably simultaneously, with the whole of the British Isles, and much of Northern Europe, an oceanic current from some north-westerly quarter prevailed, bringing masses of floating ice, with boulders upon them, which boulders were deposited on our hills (then submarine) when the ice stranded on these hills.

4. That the existence of this north-westerly current is, if not certainly proved, at all events made highly probable, by the following considerations:—

(1) That boulders of all sizes, and differing from the rocks on which they lie, *are more numerous on the west coast of Scotland* (including the Hebrides) than elsewhere.

(2) That when boulders are on hill slopes anywhere in Scotland, these slopes *more frequently face the west than any other point.*

(3) That when boulders have a longer and a shorter axis, and are narrower at one end than at the other, *the longer axis and the narrow end* very generally point towards the N.W.

(4) That when boulders are found lying against a rock, in such a way as to show that *this rock had stopped the farther progress of the boulder*, the relative positions of the boulder and of the obstructing rock imply, in a great majority of cases, transport of the boulder from the westward.

(5) That many boulders are found on or near the tops of hills, at such heights above sea-level that *no local glacier*, assuming such to have been generated in neighbouring hills, could have the positions of the boulders.

(6) That on open ground, almost everywhere in Scotland, and more especially on the west coast of Scotland, including the Hebrides, the *smoothings* and the *striations* of the rocks show a movement over them from some north-westerly point.

(7) That several plants are found on the west of Scotland and of Ireland, but nowhere else in Great Britian or Northern Europe, which plants are stated, on botanical authority, to *abound in Boreal America, as their native habitats.*

With reference to the view thus taken, that boulders in Scotland were carried on ice floated by the sea, it is curious, historically, that we should now come back to the theory suggested in this Society sixty-two years ago by a remarkable man, then President of the Society, Sir James Hall of Dunglass, whose views, however, on this subject have not always been correctly represented by geological authors. It has been alleged that in his well-known paper, dated March 16, 1812, "On the Revolutions of the Earth's Surface," published in our *Transactions*, vol. vii. pp. 139–211, Sir James sought to explain the transport of boulders by *diluvial action alone; i.e.*, by great sea waves, such as those which ingulfed Lisbon and several cities on the west coast of South America. But this is a mistake, as I should like to show, by quoting one or two sentences from his paper.

At page 161, Sir James, alluding to the different theories started by Saussure and others to account for the transport of boulders, mentions one, suggested by a Professor Wrede of Berlin, viz., that the boulders in North Germany "had been transported across the Baltic, by means of the wind on *floats of ice*, and settling in their present place, had been left there by the retiring waters."

Sir James then expresses his own opinion thus—"If the phenomena on the banks of the lake of Geneva were really occasioned by a torrent of water, its magnitude must have been such as to leave few vestiges of the human race, and we can only expect proofs of it in geological facts. It may, however, be alleged, as I have already hinted, that *it would be impossible for water of any depth whatever, or moving with any velocity, to carry blocks of such magnitude to such situations;* and this consideration is of such importance, that I am induced, in attempting to unite the ideas of Saussure with those of Hutton, to retain part of the system proposed by Professor Wrede, in so far as to consider those granite blocks as having been *made to float by means of masses of ice.*"

The opinion thus adopted and propounded by Sir James Hall was conceived at a time when nothing was known of icebergs and

icefloes in the Arctic regions carrying boulders and depositing them at a distance from the parent rocks, and is a proof of the same remarkable intuition which was manifested by Sir James in other well-known philosophical speculations.

In conclusion, and as I will probably not have another opportunity in this Society of saying so, may I express a hope that the subject of "*boulder transport*" will continue to excite interest among our members. If important truths bearing on the most recent revolutions on the Earth's surface are, as I venture to think they are, likely to be established by investigations such as those which have been for some years carried on in Scotland, and which are now carried on also in England by the Committee of the British Association, I trust that any proposal to have a new Committee will be favourably listened to. It should not be forgotten that our Society, so far back as 1812, was the first in Great Britain to bring this subject before the scientific world; and also that in the year 1871, at the instance of the late Sir Robert Christison, then our President, we again led the way in originating an extended inquiry. In these circumstances, I cannot doubt that the Society, for the sake alike of past memories, as of future probable discoveries, will be disposed to encourage further research in this interesting field of geological knowledge.

Names of Persons who were particularly serviceable to the Boulder Committee.

Clergymen.

Rev. Mr Joass, Golspie.
,, Dr Gordon, Birnie.
,, Mr Craig, Ardentinny.
,, Mr Leitteib, Cumbrae.
,, Dr Clark, Kilmallie.
,, Mr Cameron, Kilmonivaig.
,, Mr John G. Campbell, Tyree Island.
,, Mr M'Ewen, Edderton.
,, Mr M'Donald, South Uist.
,, Mr Alexander Fraser, Coll Island.
,, Mr George Campbell, Tarbet.

Schoolmasters.

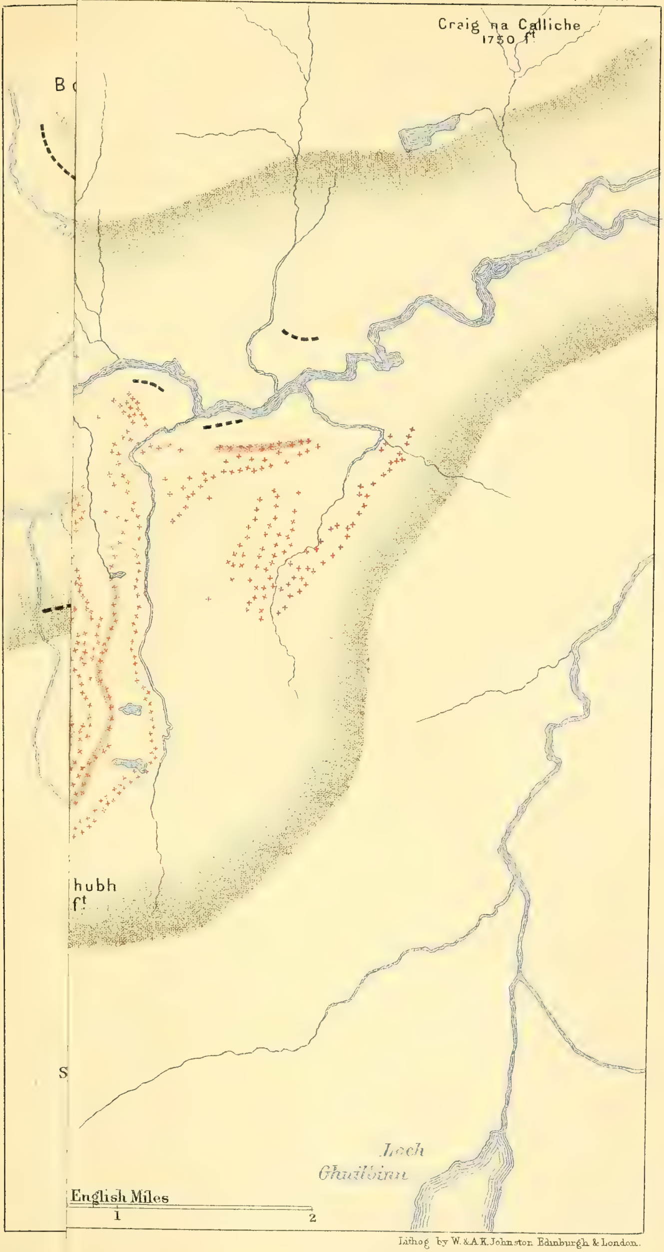
Mr Alexander, Lochgilphead.
Mr Colin Livingston, Fort-William.
Mr Martin, Elgin.
Mr William Morrison, Dingwall Academy.
Mr Wallace, Inverness High School.
Mr Campbell, Southend, Kintyre.
Mr Allan Macdonald, Iona Island.
Mr John MacKillop, Lochgair.

Landed Proprietors.

The Duke of Argyle, Inveraray.
Earl of Dunmore, Rodil, Harris.
General Sir John Douglas of Glenfinnart.
Sir John Ramsden of Ardverikie, Lochaber.
Lady Gordon Cathcart, Uist and Barra.
Clunie M'Pherson of Clunie Castle, Kingussie.
Alexander Campbell of Auchindarroch, Lochgilphead.
Edward Ellis of Invergarry, Fort-William.
J. Campbell of Stonefield, Greenock.
J. Campbell of Ormsay, Lochgilphead.
Norman M'Pherson of Eigg, advocate, Edinburgh.
J. F. Campbell, formerly of Islay, London.
Alexander Smollett of Bonhill, Dumbarton.
Captain Stewart of Coll, R.N.

Other Persons.

John Clark, writer, Oban.
W. J. Miller, C.E., Glasgow.
Mr Murray, writer, 167 George Street, Glasgow.
Alexander Carmichael, Inland Revenue officer, Oban.
Mr Ballingall, factor, Islay Island.
Mr Mackay, factor, Stornoway.
Donald M'Neill, farmer, Colonsay.
William Stevenson, Meadowfield Place, Edinburgh.
Dr M'Gillivray, farmer, Barra, Hebrides.
John Young, Hunterian Museum, University, Glasgow.



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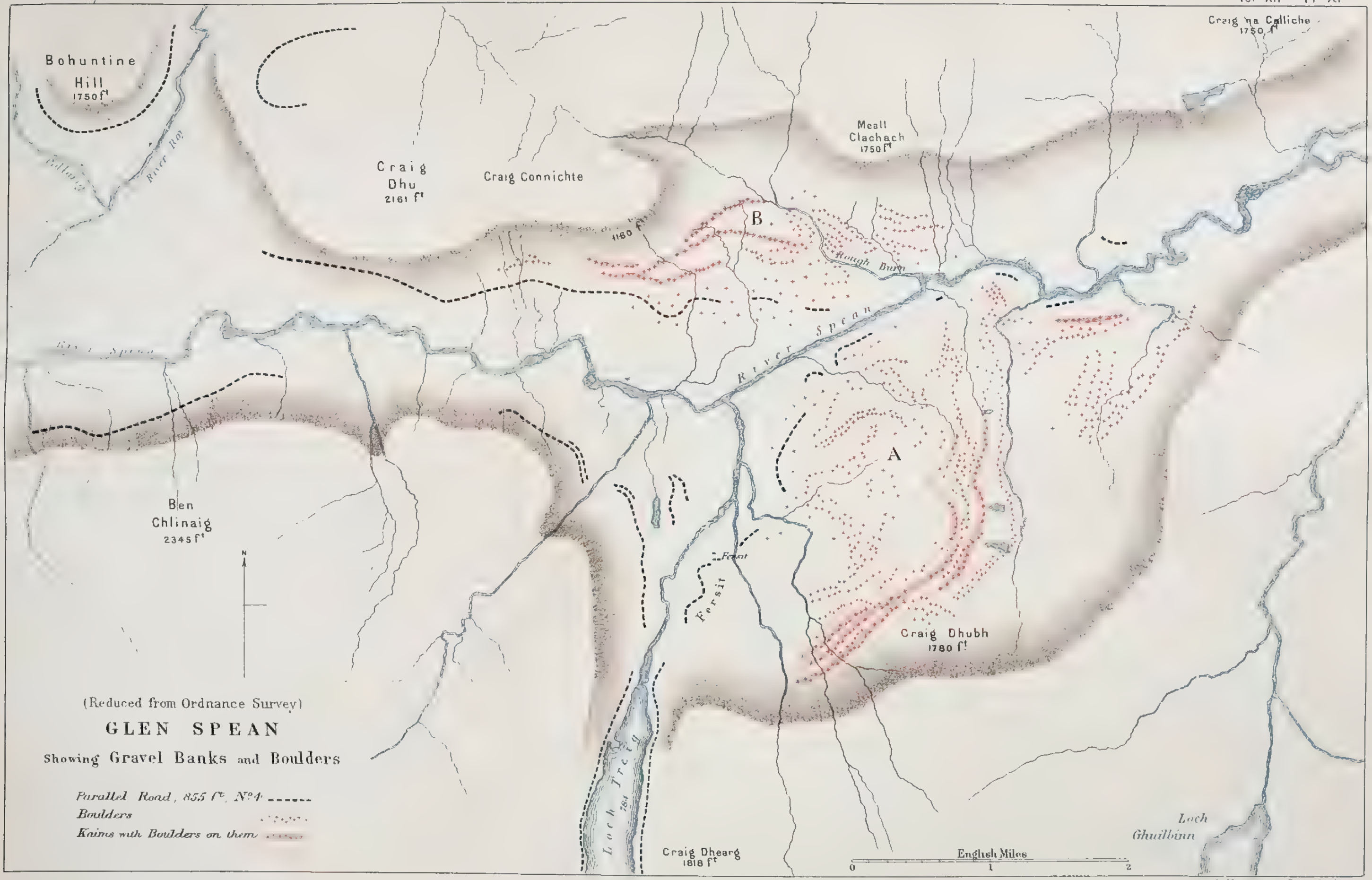

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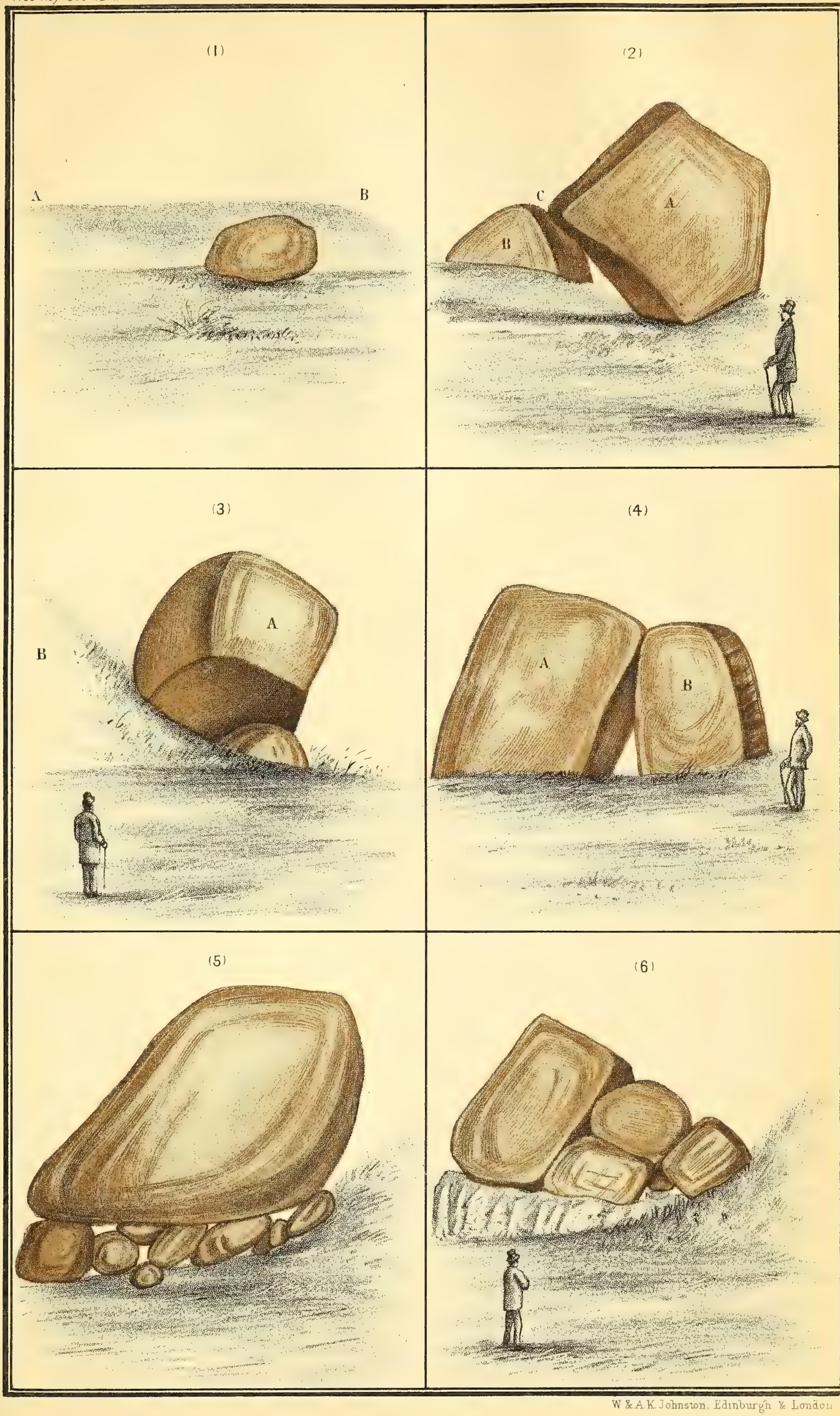
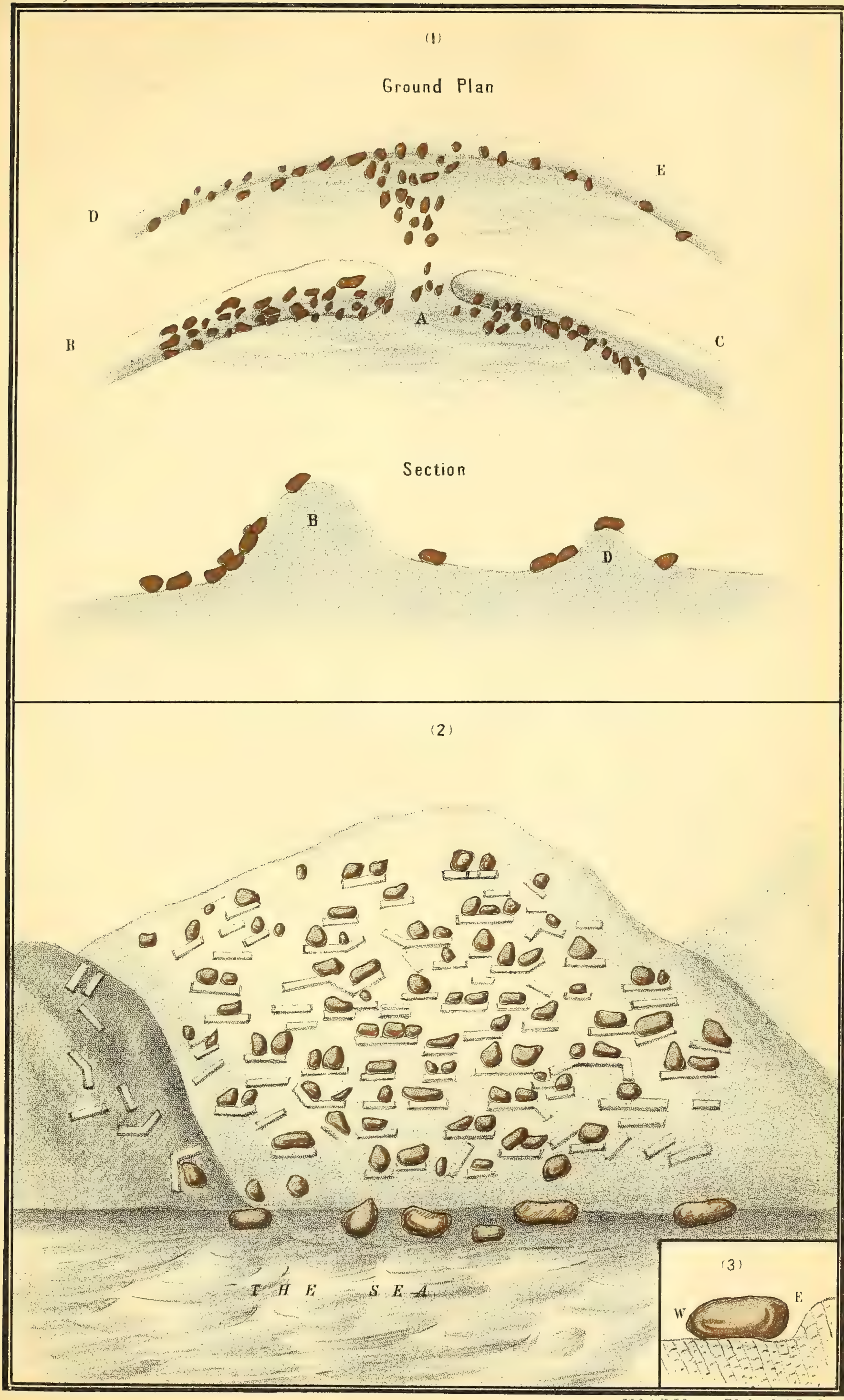


W & A.K. Johnston, Edinburgh & London



W. & A. K. Johnston, Edinburgh & London.

6. Notice of Two Localities for Remarkable Gravel Banks or Kaims, and Boulders, in the West of Scotland, in Supplement of the Boulder Committee's Tenth Report. By David Milne Home, LL.D. (Plates XI. to XIII.)

I. Lochaber.

About eight or ten years ago, when in Lochaber, studying the "*Parallel Roads*" problem, I became acquainted with a district in the valley of the River Spean, which presented the phenomena of gravel banks or kaims, and boulders, on a larger scale than I had ever before or have since met with.

The lowest of the "*Parallel Roads*," marked No. IV. on the Ordnance Survey Maps, traverses this district; and whilst tracing the direction of the "*Road*," as it crosses the lines of these banks and boulders, I was greatly puzzled to account for them, and still more for the lines in which they had been deposited. I took notes, and made rough sketches of both at the time, hoping that I might have an opportunity of a more special investigation. A failure of bodily strength supervened, which deprived me of the opportunity; but as I deem the district well worthy of the attention of geologists, on account of the light it seems to throw on questions of much interest, I propose to give a short account of the facts observed on the occasions referred to, taken from notes and sketches made at the time.

Much assistance can now be obtained for an examination of the district from the Ordnance Survey Maps. At the instance of several scientific Societies, Her Majesty's Government gave authority to the late Sir Henry James, then Director-General of the Survey, to have special maps made, to indicate the "*Parallel Roads*" in the different Lochaber valleys; and latterly, at the joint request of the Edinburgh Royal and Edinburgh Geological

Societies, he caused a map (on the 6-inch scale) to be executed of the particular districts in the Spean valley, to which I am about to refer.

This district is in that part of the valley where the River Spean, flowing from Loch Laggan, is joined by a smaller stream from Loch Treig.

The Outline Map A (Plate XI.) gives a general idea of the position of the gravel banks, with reference to Loch Treig and the adjoining Rivers Spean and Treig. The dark *dotted* line indicates shelf IV., being the lowest beach of the lake which stood at a height of about 855 feet above the sea-level. The dark *shaded* line, surrounding the valley, shows generally the position of the adjoining hills, at a level above the sea of from 1300 to 1500 feet.

I had my attention first drawn to these banks and boulders when walking along the line of shelf IV., near the mouth of Loch Treig. On looking up at the hill slope situated to the south of this loch, I noticed several projecting lines of terraces, at much higher levels than shelf IV., and at first thought that they might represent some of the shelves of the higher lakes, which had been recognised in other Lochaber glens, but not in this one.

I thereupon ascended the hill, and, on doing so, obtained a general view of the low grounds, and of the remarkable assemblage there of kaims and boulders. I at once saw that many of both formed lines, in some cases *rectilineal*, but also and even more frequently *curvilineal*, the inner curves facing the north, *i.e.*, down Glen Spean. (See A on Sketch Map, Plate XI.)

The first terrace on the hill slope which I reached was (by aneroid) at a height of 1120 feet above sea-level. The terrace presented a level surface from 40 to 50 feet wide, abutting against the hill, and was composed of water-borne gravel. Two great boulders lay on this terrace, about 200 yards apart.

From this terrace I climbed to another, at a height of 1165 feet above sea-level; on it were three large boulders.

There was still another terrace, and its height above the sea I found to be 1175 feet.

Again a higher terrace was reached, 1480 feet above the sea, somewhat broader than the others, and having a considerable number of boulders on it.

I did not observe any terraces at a higher level; but I saw that there were many boulders on the slope of the hill above, some of large size.

With the view of proceeding next to the low grounds, where the extended lines of kaims and boulders were seen to be situated, I walked south along the highest of the above terraces, and observed that it gradually ceased to touch or abut with a flat surface on the hill, and that it became separated from the hill by a narrow trough, as if the detritus next the hill had been scoured out by the action of water currents, or of rain descending on it from the slope of the hill. The terrace at length became so narrow as to become a bank or ridge, the outer flank of which was, of course, much higher than the flank next the hill.

The upper surface of the terrace now ceased to be horizontal, and sloped down towards the S.E. As I proceeded, I observed, on my right hand, some rocks much smoothed, at a height of from 1500 to 1600 feet.

A little further south, I came to a projecting rocky corner of the hill, named *Craig Dhubh*, indicated on the one-inch Ordnance Map by the sudden bending of the contour lines towards the S.W. The surfaces of the rocks there were seen to have been greatly smoothed (apparently from the north), whilst immense masses of rock were lying at the foot of the crag. It was only at this corner of the hill that any smoothing of these masses existed. Rocks continued in a S.W. direction without any such features. The agent which had produced these effects had, at this point, apparently slanted off towards the S.E.

Before descending further, I looked with my glass across the valley towards the hills on the east, and descried there several lines of terrace on the south projecting shoulder of *Craig Dhu* and *Connichte*, and also on some high ground near the *Rough Burn* (Sketch Map B, Plate XI.). These I decided on visiting, after inspection of the low grounds immediately below me.

In my way towards the low grounds A, I walked along a kaim or gravel bank, whose course followed a direction about E.S.E., and sloped downwards, with steep sides from 20 to 30 feet high. I observed that there were also many boulders on the low grounds, some of them forming lines or *trainées*.

The district occupied by these kaims was tolerably flat, and about $2\frac{1}{2}$ miles wide (in an east and west direction) across the general course of the River Spean.

There were several lines of kaims all approximately parallel, and presenting a slight curvature;—the inner curves facing the north, or down the valley of the Spean.

At one place there was an interruption in the continuous line of the northernmost bank, as if it had been broken through by some agent from the north; and I took a rough sketch of it on the spot, being fig. 1 on Plate XIII.

At A, the kaim BC ceases for about twenty yards; and between this "break," and the other bank DE, there is a heap of boulders.

The highest and thickest of the two banks is BAC, and on it the greatest number of boulders are accumulated.

On the low ground to the north of these kaims there are many grey granite boulders of various sizes scattered about, mostly angular.

There two knobs about twelve or eighteen feet high attracted my attention, in consequence of there being boulders on their tops. One of the knobs was of *detritus;* the other of *rock*, sloping down steeply on all sides, except the east.

In each case the diameter of the flat surface at the top was about six or seven yards, and there were five or six boulders on each;—most of the boulders were on the sides facing the N. and N.W.

In several places, and especially at the north base of the most northern kaim, BAC, there were boulders piled over one another. On studying these, I became impressed with the belief that the uppermost boulder, being the last which came, should show the quarter from which it must have come, to get into its position.

Diagrams on Plate XII. represent these cases, showing that the boulders had come from some northerly point.*

There was one place where *rocks in situ* of grey granite were found smoothed; the smoothed face being towards the north, and a boulder lying on that side. The farther progress of the boulder to the south had been apparently obstructed by the smoothed rocks. This case is shown by fig. 1, Plate XII.

* Explanations of the Plates are appended to this notice.

On several occasions subsequently, I examined the banks and boulders, occupying the district on the east side of the River Spean, and situated to the north of the spot on the Ordnance Map called "*Rough Burn.*" (See B on the Sketch Map, Plate XI.)

I found several, and especially two remarkable kaims, running in a somewhat different direction from those on the west side of the valley, viz., towards south, and curving like the rest,—with the inner curve facing the west. I walked along the top of the two highest kaims. Their sides were steep, and reached in some spots to a height of 30 to 40 feet, with many boulders on them.

These kaims occupy portions of the hill, which slopes up towards the north, from about 1100 to 1245 feet above sea-level.

Standing on these kaims, I could descry Loch Treig, which by compass bears from them about S.S.W. The level of the loch is represented in the Ordnance Map as 784 feet above sea-level.

Some of the boulders, on the level ground in several parts of the valley, form *trainées*, more or less parallel with the lines of the kaims.

The following are the dimensions of some of the boulders on the east side of the valley :—

One measured in girth 19 paces, and in height 5 feet.

Another measured 12 × 3 × 2 feet, with longer axis S.W.

" 15 × 10 × 4 feet, " "

It is proper to add, that shelf IV., before referred to as the beach line of the lowest lake, is visibly impressed on the gravel banks, on both sides of the valley; and they are so indicated on the Ordnance Map.

These kaims, therefore, belong to a period in history more ancient than the Lochaber lakes.

Theory.

With regard to the origin of these banks and boulders, there can be little or no doubt that the materials of the banks, consisting chiefly of well-rounded pebbles and blocks, and in some cases of sand, in beds partially stratified, must be due, in some way, to the agency of water, with deep and powerful currents.

The detritus had assuredly not fallen from the adjoining hills, by the natural decay of the rocks composing them.

The late Dr Macculloch, who was eminent as mineralogist, geologist, and chemist, visited Lochaber, to seek for data to enable him to try and solve the problem of the parallel roads; and wrote an elaborate paper on the subject, which was published in the *Transactions of the London Geological Society for* 1817, vol. iv.

He particularly studied the nature of the gravelly materials lying on the surface of the country, and he found that these were of two descriptions. He observed that the debris of the rocks were angular in shape:—The other class he called "*transported alluvium of pebbles, sand, and gravel;*" and these, he observed, generally differed in mineralogical composition from the rocks of the hills on which they lay. "The *alluvium* (he says) was not thus *rounded* by the action of the *water which produced the lines* (*i.e.*, the parallel roads). We must suppose that this *rounded alluvium* had been, by *previous* causes, accumulated. If this took place from the action of water (*and to what other cause can we assign it?*), it must belong to an epoch prior to the deposits of sharp matter in the upper parts" (page 330).

Again he says:—"The conoidal hillocks, occurring between Glen Fintec and Glen Glastrie, *consist of deposits of fine sand, clay, and rolled stones* of different sizes,—disposed in a manner *irregularly stratified*, and in a direction more or less *horizontal.* The terraces and hillocks, which occupy positions much inferior to these, *all the way along the course of the Spean, are of the same materials*" (page 339).

The hillocks in Glens Fintec and Glastrie, here mentioned as examples of "*transported alluvium,*" occupy positions exceeding 1200 feet above the sea, and are (Macculloch says) the same kind of deposits as those along the course of the Spean, referring, no doubt, to the kaims described in this paper.

Examples of these detrital deposits occur in all the Lochaber glens. In *Glen Roy* and its lateral valleys, there are cliffs of boulder clay, exceeding 200 feet in depth. Along the course of the Spean at *Murlaggan*, on the east bank, there are cliffs of sand, partially stratified horizontally, above 80 feet deep; and on the west side,

at *Alt-na-Bruach*, there are cliffs of mixed sand and gravel, equally deep, all more or less stratified.

The River Treig, near its exit from the loch, has cut through banks of gravel, also stratified, exceeding 70 feet in depth.

It may be added that any one passing through the Caledonian Canal, near Banavie, may see great gashes on the Moy Hills to the north, occurring in enormous beds of white sand, at a height of 2000 feet above sea-level.

Mr Jamieson of Ellon examined the whole of this district carefully, and mentions that at the outlet of Loch Treig he found "striæ running horizontally along the face of the rocks up to 2000 feet;" and he adds, "not that I affirm even this to be their upper limit." He mentions similar features, even as high as 3055 feet above the sea, "which (he says) raise a suspicion that *some denuding agent has flowed over it* at a period geologically recent." (*Lond. Geol. Soc. Journal*, 26th Feb. 1862, p. 172.)

In these circumstances, it seems impossible to doubt that the sea has flowed over the whole of this district, and in such a way as to bring detritus of sand, mud, gravel, and boulders, and deposit them alike on hills and in valleys. The detritus which forms the kaims in the Spean valley, which I have been describing, must therefore almost certainly have been brought and deposited there by oceanic agency.

The gravel banks or kaims of the Spean valley are not unexampled in many other parts of Scotland. In Linlithgowshire a gravel bank, with steep sides, runs from Polmont eastward, nearly two miles continuously, with occasional bends, and is now cut across at several points by small rivers. In Haddingtonshire a similar east and west kaim runs for about a quarter of a mile. In Nairnshire there is a similar kaim, traceable for a greater distance. In Berwickshire, on Greenlaw Muir, at a height of about 1000 feet above the sea, there is a gravel bank, high and steep, about three miles in length, presenting several *considerable bends in its course*, and cut across by two small streams.

In consulting the Admiralty Maps, which show the forms of submarine sandbanks, I find many examples running for more than a mile continuously, and, in one case, a bank *curved into almost a semicircle*. Off the mouth of the Thames, where the tidal currents are strong, there are several such cases.

When Scotland was submerged, the currents in this region would probably be rapid, looking to the relative positions of the hills and valleys.

If the question be thought of any importance, it may be noticed on the Map, Plate XI., that this part of the Spean valley is so surrounded by hills, as to be an area well fitted for the reception and detention of detritus, its diameter being about three miles.

Moreover, it is worthy of notice that the valley in which this area occurs is contracted at its north end, so that if a current flowed at that end, towards the Spean valley, it would enter the valley with considerable velocity, and in virtue of the way in which it is surrounded by hills, it might acquire a circular motion, producing whirlpools or eddies.

It will be found, on consulting the contour lines of the one-inch Ordnance Map, that whilst the space where the kaims and boulders are situated is (between the contour lines of 1250 feet) three miles across, the breadth of the valley to the north, between the same contour lines, is only $1\frac{1}{2}$ miles (see Sketch Map, Plate XI.). To the north of this gorge there is open country, and at a low level; so that if the country was then submerged there would be opportunity for a large body of water flowing through the gorge towards the south.

Now it is allowable here to observe that there are strong reasons for believing that when Scotland was submerged a powerful current, with floating ice from some north-westerly point, did prevail here, as probably elsewhere in Scotland. A few of the facts bearing on this point may be mentioned.

(1) The most important of the lateral glens joining Glen Spean is *Glen Roy*, which runs for about 16 miles towards its head or col in a S.E. direction. I extract the following paragraph from the notes taken by me when I visited this glen in 1846 :—" Visited head of Glen Roy. In upper Glen Roy it is interesting to observe how uniformly the *smoothed* surfaces of rocks are to the *west*, and their *rough* faces to the *east*."

As this is a point of some importance, I confirm my own observation by a quotation from the Memoir of Mr Jamieson of Ellon, who, with a view to the "Parallel Roads" problem, made an elaborate survey of all the Lochaber glens. Near the top of Glen Roy, he

says (*Lond. Geol. Society's Proceedings*, vol. xviii. p. 296)—"I was not a little surprised to find that the ice had come from the S.W., *i.e.*, *up* Glen Roy. . . . . . The strata had been so *blunted* and *rubbed on their S.W. exposures* as to show plainly that the movement came from *that* quarter; and high up on the brow of the adjoining hill I saw several very large blocks and boulders that appeared to have been shifted or moved some distance . . . . . by glacial action."

Mr Jamieson suggests that this rubbing of the rocks, on their S.W. exposures, was due to "glacial action." If ice moved up the glen it could not have been glacier, but floating ice.

(2) In *Glen Gluoy Valley*, adjoining *Glen Roy*, and opening like it towards the west, similar proofs exist of a movement *up* the glen, from the westward (see "Memoir on Parallel Roads," *Edinburgh Royal Society Transactions*, vol. xxvii. p. 638).*

(3) *Craig Dhu*, a hill situated on the *east* side of the gorge before mentioned, reaches to a height of 2100 feet, and presents several spots near the summit on its N.W. side, where the edges of the strata show smoothing from the north. The boulders on the hill are also chiefly on the north slopes.

(4) *Ben Chlinaig* is a hill on the *west* side of the gorge, reaching to a height of 2545 feet. Mr Jolly of Inverness informed me that on its eastern slope he found rock striations at a height of 1840 feet, running N.W. and S.E.

(5) In the gorge itself, near its lowest level, some of the rocks present large smoothings facing the north, and grooves of great length, evidently caused by violent and severe friction of heavy bodies which had moved over the rocks.

(6) Then on the N.W. shoulder of *Ben Nevis*, at the mouth of

* As these pages were being printed, I received from my old and esteemed friend, Colin Livingston of Fort-William, a letter (dated 23rd September 1884) narrating an excursion he had a few days previously made to *Glen Gluoy*, and mentioning that at a height of about 1750 feet above the sea he had found several granite boulders on the side of a hill facing the west, and lying on quartzite rocks, which were smooth on their west sides and rough on their east sides. He adds that three of these boulders formed a line or *trainée* of abou a 100 to 120 yards. He became satisfied, from these facts, that the boulders had come *up* the glen from the westward, and not *down* the glen, as he had previously supposed. The nearest locality for granite rocks, known to him, is "*Meallan-Suidhe*," situated some miles to the westward.

a glen called *Corry N'Eoin*, I found, at two different spots, rocks so striated as to show that the striating agent had moved from N.N.W., *i.e.*, in the direction of the Spean valley.

(7) In the Spean valley itself there are at least a dozen places where the rocks by the marks on them distinctly show severe pressure and friction by some body passing over them in a S.E. direction.*

(8) Reference having been made to terraces or banks of detritus on the slopes of the hills to the south of *Loch Treig*, up to a height of about 1400 feet above the sea, it is proper to mention that similar banks of detritus occur on the hills to the north, and at about much the same level.

On *Chlinaig Hill* (before referred to) there are two such banks at a height above the sea of 1253 feet and 1373 feet.

The hill on the opposite or east side of this valley shows similar banks, and along which I walked at rather a lower level.

It appeared to me that these had very probably been formed when the land was submerged. They are essentially different from the old lake beaches, in respect of their want of horizontality.

(9) Lastly, I refer to the fact, that almost at the very tops of the highest adjoining hills great boulders are found, and in such positions as to show that they could not have come there except by floating ice. Thus, Darwin refers to the boulders on the top of hills in Lochaber, at the heights of 1700 and 2200 feet above sea-level. On the tops of two hills adjoining Loch Laggan, exceeding 3000 feet above the sea, I was informed by Sir John Ramsden of Ardverikie, the proprietor of these hills, that there are several large granite boulders.

Whilst expressing my own opinion that the kaims and boulders in the valley near the junction of the Rivers Spean and Treig indicate the agency of the sea, it is proper to advert to the opinion of my geological friend, Mr Jamieson of Ellon, that these are the *moraines* of a glacier which, generated in Glen Trieg, advanced into and crossed the Spean valley.

Mr Jamieson adopted the view originally suggested by Agassiz, that the barriers of all the old Lochaber lakes consisted of ice. It being necessary to find a barrier for the Glen Roy Lake not only

* These places are named in the "Memoir on Parellel Roads," by Professor Prestwick and me respectively.

at the foot of the glen, but at the head of Glen Glaster, Mr Jamieson saw that the only way of obtaining an ice barrier at this last-mentioned place was to assume the existence of a glacier in Glen Treig, which he supposed would descend into and cross the valley, then rise up on the opposite side of the valley near the Rough Burn, and next make a nearly right-angled wheel towards Glen Glaster, distant from Loch Treig no less than 6 miles !

I am afraid that I must agree with Professor Prestwick (*Phil. Trans. of Royal Society of London for* 1879, p. 668) in the opinion he has expressed, that the "Glen Treig glacier would be *incompetent to the task assigned to it*" by Mr Jamieson. Professor Prestwick observes, that to block Glen Glaster col the "glacier would have to cross Glen Spean, and after that travel 2 miles with a rise of not less than 500 feet."

I agree with the Professor (page 684), that if there was a glacier from Glen Treig, which protruded into the valley, it would, instead of ascending the slopes on the opposite or east side of the valley, have followed the natural levels of the valley, and flowed down towards the north-west.

Whilst Mr Jamieson's primary object in suggesting a Glen Treig glacier was to find a barrier for the head of Glen Glaster, he also availed himself of the services of this glacier for explaining the origin of the kaims and boulders, which form the subject of the present paper.

One fatal objection to this view, as it appears to me, is, that the *materials* composing these kaims are not such as characterise moraines. They are what Macculloch properly calls "*rounded alluvium*," formed by the action of water; whereas the materials of moraines being merely the débris of rocks, which fall on the surface of the glacier by meteoric agency, are totally different in character.

Another objection to this view is, that the lines of kaims in the valley lie to the south of the march which any glacier from Loch Treig would take. To meet this obvious difficulty, Mr Jamieson says that "the glacier on issuing from the narrow gorge at the end of Loch Treig *dilated immensely;*" so that its *right flank* might carry materials to the position occupied by the kaims and boulders. I think that if the glacier underwent such an immense

dilatation, it would fall to pieces altogether in the valley, before it could reach the position of the kaims.

At the same time, I am far from denying that Mr Jamieson had good grounds for supposing that a small glacier existed in Glen Treig, and that it even probably protruded a little way into the valley.

In his map he indicates glacial striæ at a point where they may have been caused by a glacier from Loch Treig. I saw these striæ, (Notes, vol. i. p. 8), viz., on masses of rock which had been smoothed and partially striated from the westward. Most of the rock was covered and concealed by detritus, which, on being cleared away by me, showed the smoothed surface of the rock. The explanation which occurred to me at the time was, that after these rocks had been so smoothed and striated the country became submerged, and the whole valley was filled with submarine beds of gravel, sand, and boulders. The spot now referred to is near that marked "*Fersit*" on the one-inch Ordnance Map (Sketch Map, Plate XI.).

Whilst offering my opinion, that these kaims in Spean valley are submarine detritus, and have been scoured out into long banks by the action of sea currents, I acknowledge that they deserve much more examination than I had the opportunity of giving; and I trust others who are interested in these researches will visit the locality, and publish the results of their inspection.

Harris.

In the Fifth Report (page 23) of the Boulder Committee it is mentioned that "at *Borve*, on the west coast of Harris, about half-way between Rodel and Tarbert, there is a remarkable accumulation of boulders on the side of the hill sloping down to the sea. The general slope of the hill (which reaches a height of 800 feet) is towards W. by N. (magnetic). The rocks are of gneiss, and present a series of beds, layers, or benches more or less horizontal, forming as it were a gigantic staircase along the hill face, for about half a mile, all more or less covered by boulders. These benches of rock, in many places, show that they have been rounded by severe pressure from W. by N. Many of the boulders which lie on them also give evidence of transport from the west."

Two figures are appended to the Committee's Fifth Report, to illustrate these facts.

But I happen to have in my possession a more graphic representation of the locality, which I now exhibit to the Society. It was made, at my request, by a London landscape-painter, who was taking views at Harris, and whose acquaintance I happened to make, by residing in the same inn with him. He and I on one occasion travelled together in the same conveyance, and had to bait our horse at Borve, near which the hill occurs. He saw me vainly endeavouring to make in my sketch-book a drawing of the hill; and, at my request, he was so kind as to give a representation of the place in my sketch-book, which I now reproduce (Plate XIII. fig. 2). It shows how numerous the boulders are on the hill-slope, and that they had found lodgment on the ledges of gneiss rocks which protrude from the hill.

I give also a representation of one of the boulders (Plate XIII. fig. 3), firmly lodged on the projecting strata of the hill; its east end abutting against the strata in such a way as to show that it had probably come from the westward.

The interest of the locality arises from the circumstance that the hill on which those boulders lie slopes down in a westerly direction to the Atlantic Ocean; so that if the boulders on the hill came from the westward, as I think they did, they must have been transported from some land bordering on the Atlantic.

EXPLANATION OF PLATES.

Plate XI.

A sketch map reduced from Ordnance Survey, to show part of Glen Spean valley, with lines of kaims and boulders.

Plate XII.

(1). Map of smoothed granite rock in Glen Spean valley, AB, running in S.W. direction, and having its smoothed side fronting N.W., with a boulder pressing against it.

Loch Treig bears W.S.W. from the rock; whilst lower part of Spean valley bears N.W. by W. from the rock.

If boulder came from Loch Treig it would not have been intercepted by the rock, but have passed on to left, viz., in a N.E. direction.

If boulder came up Spean valley it might have been, and most probably would be, obstructed in its farther progress by the rock.

(2). Boulder A rests by one of its corners C on boulder B. A line drawn through centre of A and corner C points S.E. by S., implying transport from N.W. by N. If boulder A had come from Loch Treig it could not have stuck on boulder B, but have fallen off to one side.

(3). Two boulders resting on north side of a gravel bank in Spean valley. If these boulders had come from Loch Treig they probably could not have stuck there.

(4). Two large boulders in Spean valley, situated S.E. of Loch Treig. Boulder A leans against boulder B in such a way as to show that it came from the north, and not from Loch Treig. Moreover, a hill on south side of mouth of Loch Treig is so high that it would have prevented these boulders reaching positions they occupy.

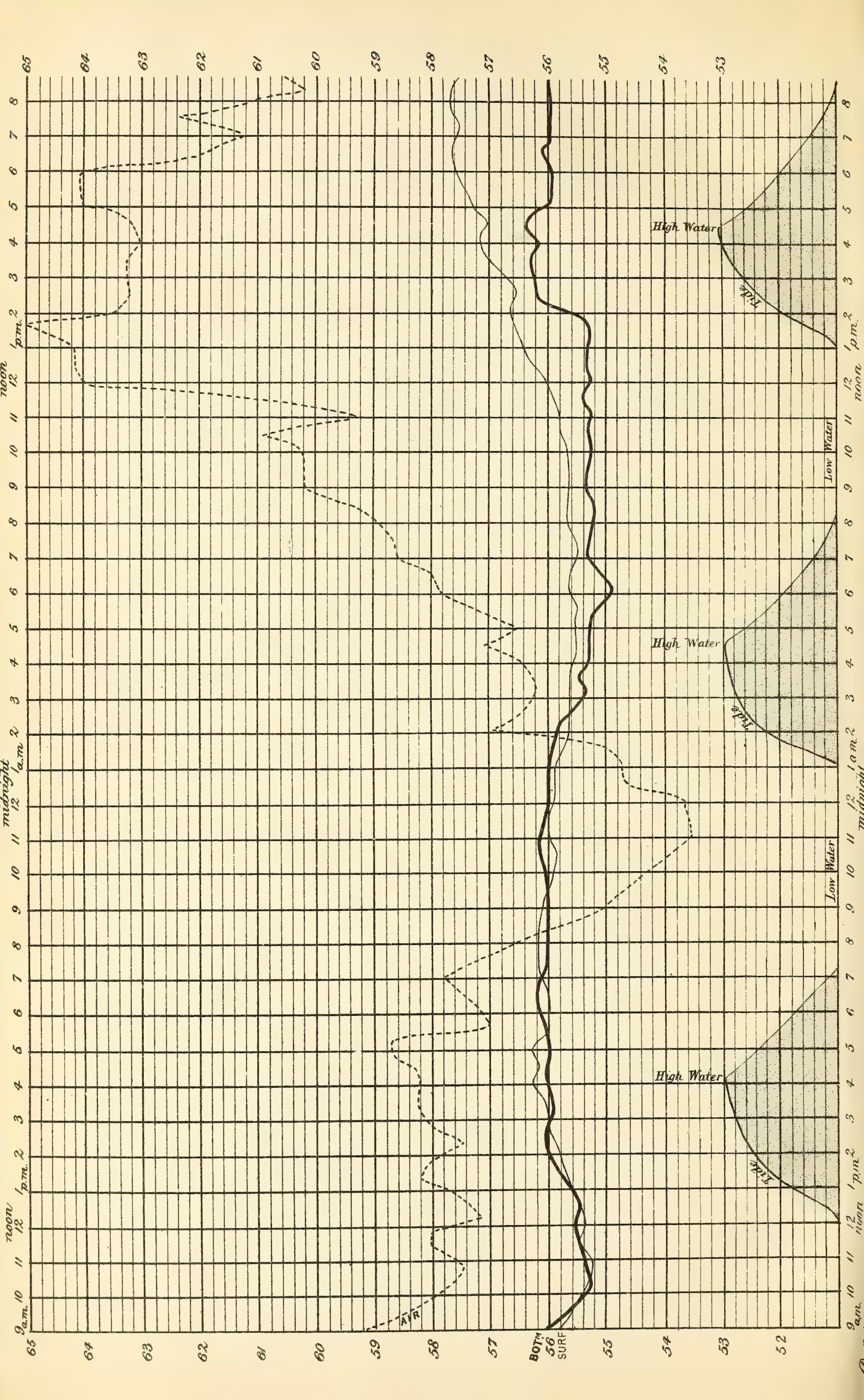
(5) and (6). Boulders at north side of a gravel bank in Spean valley.

Plate XIII.

(1). Is intended to represent a small portion of two kaims with boulders on their sides, facing the north. The most northern shows an interruption at A, as if it had been broken through by some agent from the north.

(2). Represents a hill near *Borve* (in *Harris*) sloping down to the sea-shore, covered with boulders, apparently brought from a sea-ward direction, viz., the west.

(3). Is one of many boulders on Borve Hill, resting on the rocks in such a way as to show transport from a westerly point.



Corrected Temperature Curves for Granton Quarry, June 25th and 26th 1884 Station I. The Ark (Port bow)

7. On the Periodic Variation of Temperature in Tidal Basins. By Hugh Robert Mill, B.Sc., F.C.S. Communicated by Professor Crum Brown. (Plate XIV.)

The periodic variations of the temperature of water have been studied for some months at the Scottish Marine Station at Granton. The only tidal basin which has been considered as yet is the haven formed by the irruption of the sea into Granton Quarry. It has an area of about 7 acres; the tidal entrance is on the west side, and is so situated that no water can enter until about half tide; then it comes in as a very rapid stream for about three-quarters of an hour, when the rate falls off, and near high water it is the same as that of the rising tide on the shore. The ebb is gradual until the tide has narrowed the channel by uncovering the sandbanks which lie on each side of the entrance, then it is rapid for about an hour and a half, after which the water runs out extremely slowly, and does not absolutely cease until the tide begins to re-enter; but for from four to five hours the water-level inside is practically unaltered. The depth of the quarry at low water varies from 5 to 8 fathoms in the parts where observations were made, and at high water the depth is slightly more than 1 fathom greater. The bottom shelves off abruptly from the bar at the entrance.

The variation of water temperature naturally divides itself into two periods—annual and diurnal. The former can only be ascertained by daily observations continued for several years, and such observations of both surface and bottom temperature were commenced in May 1884, and are being continued. The diurnal variations may be investigated by continuous hourly observations for a number of entire days. Such series of hourly, and in some cases half-hourly, observations were made twice in the month of June for periods of thirty-six hours each, and once in the beginning of July for twenty-five hours, and some interesting facts were brought out by this means.

It was made evident in some preliminary trials that the Miller-Casella thermometer was not adapted for rapid work in shallow water. It requires to be immersed from ten to fifteen minutes in

order to acquire the temperature of its surroundings; when drawn up from depths under 10 fathoms, the mercury has not had time to recede from the index, and before it can be read evaporation from the wet bulb lowers the temperature and renders the reading inaccurate.

Sir Robert Christison's cistern thermometer gave good results, but it is too heavy an instrument to use continuously for many hours.

For the first two sets of observations about to be described Negretti and Zambra's patent deep-sea thermometer with Magnaghi's frame was used. The instrument is constructed so that after it has acquired the temperature of the water it may be turned over; on this being done the mercury which has passed out of the bulb runs into the upper part of the tube which is now lowermost, and can be measured by means of a scale of degrees when the instrument is drawn up. It contains only one fluid—mercury; and experiment has shown that three minutes are sufficient to enable it to acquire the temperature, although in our observations it was customary to allow four or five minutes as a minimum to make sure. The reversing arrangement of Magnaghi resembles a screw-propeller; it is turned on drawing the instrument up through the water and releases the thermometer, which then turns over, as its pivots are below the centre of gravity and it never hangs quite perpendicularly. The objection to the method is that in shallow places the temperature at the bottom cannot be obtained, since the reversing screw will not act in much less than a fathom of water under the most favourable circumstances, and usually it requires considerably more. A modification of the thermometer was accordingly designed by Professor Chrystal and myself, and the necessary alterations were made in a most satisfactory manner by Mr Frazer of Lothian Street.

The Scottish thermometer-frame, as the improved form has been named, differs from Magnaghi's by the removal of the screw and fans from the pin that holds the thermometer in position, and the substitution in their place of a lever kept down by a spiral spring. The lever is forked at the outer end to allow the line to which the thermometer is attached to pass between. In order to prevent the line from slipping out of the fork, it is clasped by two thin springs

which rise from a projecting horse-shoe-shaped piece beneath the lever. A hollow cylindrical weight slightly belled out at the lower end is dropped down the line when the thermometer is to be reversed; it falls on the forked lever, raises the pin, the upper end of the instrument gets an outward impulse from an india-rubber band slipped over the frame (a device of Mr Buchanan's), and it rotates sharply, and is clamped by a brass spring. When several of these thermometers are used on one line, as is convenient in taking serial temperatures, the weight for the next lower instrument is hung by a wire to the groove in the top; it helps to pull the thermometer over when released, then sliding down the line it strikes the lever of the next, reverses it, and despatches its weight. In this way any number of instruments may be used on one line. The ends of the lever forks are covered with india-rubber to diminish the shock, and the whole apparatus is constructed of brass, so that no galvanic action can be set up between any of its parts.

The adaptation of the Negretti and Zambra thermometer to reverse by means of a weight slipped down the line is not new. Mr Rung, of the Meteorological Institute of Copenhagen, has invented a very simple method of doing this; but, although his frame has worked admirably in his hands, it has the disadvantage of being constructed of wood. A simpler arrangement for the same purpose was employed on the United States ship "Fish Hawk;" but, from the account given of it, it seems to be inferior to the Scottish frame, in not clamping the instrument when reversed. The new thermometer was made before the description of either of these earlier forms was seen. It has been found to answer admirably, both in very shallow water and in depths up to 80 fathoms.

The first set of observations was made hourly during a period of thirty-six hours, from 9 A.M. on June 17th to 9 P.M. on June 18th. The temperature of the air, of the water at the surface (by an ordinary thermometer), and at the bottom, were taken each time from the Ark, the floating laboratory of the Station. The mean temperatures (corrected) were as follows:—

	For 30 Hours Daylight.	For 6 Hours Darkness.	For 36 Hours.
Air, ...	58·7	54·1	57·9
Water, surface, . .	54·98	54·88	54·97
Water, bottom, . .	54·60	55·01	54·67

The observations included two complete tides, and it was observed that when the water began to enter at 6 P.M. the bottom temperature began to rise from 54° until at 9 P.M. it reached 55°. The surface temperature was meanwhile falling. The night was cloudy, and from 9 P.M. to 6 A.M. the readings of the surface and bottom thermometers were practically the same. At 6 A.M. the tide began to enter, and the bottom temperature fell slowly from 55° to 54°·6. The whole of the next day was dull and cloudy, and the temperatures of air and of water varied little. The tidal effect observed was somewhat puzzling, for the temperature of the water of the Firth was known by previous observations to be several degrees lower than that in the quarry, and not to vary appreciably with the hour.

In order to get additional evidence, the 25th and 26th June were selected for another series of observations. The 25th was cloudy and cool, the air temperature being altogether below the average for the two days, the night was pretty clear, and the 26th turned out bright and warm. As I had more assistance than on the former occasion, observations were made every half hour at three stations in different parts of the quarry—one near the mouth where the depth at low water is 5 fathoms, the second was the Ark in 6 fathoms, the third a buoy in the north-west corner in 8 fathoms. The means of the observed temperatures are as follows :—

		For 30 Hours Daylight.	For 6 Hours Darkness.	For 36 Hours.
Air,		59·5	54·9	58·6
Surface	Entrance,	56·61	...	...
	Ark,	56·17	55·52	56·05
	N.W. corner,	56·52	...	...
Bottom	Entrance,	55·51	55·65	55·55
	Ark,	55·74	55·97	55·64
	N.W. corner,	54·92	55·82	55·24

The course of the temperature curves at the Ark on those two days is shown in Plate XIV., where the tidal effect is plainly noticeable. The observations embraced three complete tides. When the water began to enter at noon, there was a steady rise of bottom temperature, and when it entered at 1 A.M. next day there was as distinct a fall; while on its coming in at 1.30 P.M. a very abrupt rise of almost a degree was observed at each of the stations. The curve of surface temperature followed that of air temperature in the main, as on the previous day.

The improved thermometer having been constructed and tested in the interval, a set of hourly observations was made at the three stations during a period of twenty-five hours, from 9 A.M. on July 3rd to 10 A.M. on July 4th. The temperature was taken at the surface and the bottom as on previous occasions, and also at a point midway between the two.

The third was a hot clear day, but the sky clouded in the evening, and rain fell very heavily during the entire night. A severe thunderstorm was experienced from 11 P.M. on the 3rd to 4.30 A.M. on the 4th. The continual dazzling produced by the lightning flashes made it difficult to read the thermometers with accuracy, but there is reason to believe that no serious error was made, and the observations were carried on regularly.

On the third the surface temperature was high, and the intermediate curve remained close to the bottom one, until 5 P.M., when it rose rapidly. During the night and on the forenoon of the 4th, the temperature varied but little, and the curves for the surface, bottom, and half depth interlace each other curiously. A distinct rise of the bottom temperature, and fall of that at the surface, marks the inflow of the tide at 8 P.M. The means for this set are—

		19 Hours Daylight.	6 Hours Darkness.	For 25 Hours.
Air, ...		57·6	55·2	57·0
Surface	Entrance, .	57·95	57·36	57·78
	Ark, . .	57·73	57·35	57·65
	N.W. corner,	58·10	57·41	57·90
Half-depth	Entrance, .	57·59	57·48	57·56
	Ark, . .	57·31	57·47	57·35
	N.W. corner,	57·23	57·43	57·29
Bottom	Entrance, .	57·19	57·49	57·27
	Ark, . .	57·20	57·30	57·22
	N.W. corner,	56·93	56·83	56·92

In order to eliminate the tidal effect as much as possible, a mean was taken of the hourly results of the first and second series; the tides, being at opposite phases at the same hour, annul each other to a certain extent. The surface temperature curve in the diagram, representing the result of tidal elimination, follows the air curve very closely; the bottom curve also does so, though to a much slighter extent, and the phase is clearly retarded. The accurate curves embodying all the results have been laid on the table.

It is obviously unsafe to generalise from such a small number of observations, but the results brought out by the discussion of the figures may be stated as at least probably true :—

(1) During daylight the air was always at a higher temperature than the water, but after sunset the water was warmer than the air; and taking an average for the whole period, the mean temperature of the air was the higher.

(2) The surface temperature followed that of the air, and was little affected by tidal changes.

(3) The bottom temperature followed that of the air, but the crest of the heat wave was retarded by several hours, and the curve was profoundly modified by the tides.

(4) The temperature was higher at the surface than at the bottom during the day; but, as a rule, it was higher at the bottom than at the surface by night.

(5) When the tide flowed in the early morning it exercised a cooling effect on the bottom thermometers, but when it flowed at other times it produced a warming effect.

The variations of temperature when the tidal effect is eliminated may be accounted for by the direct action of sun heat and radiation, propagated by conduction and convection beneath the surface. It is possible that when the tide enters the quarry after the sand over which it must flow to reach the entrance has been exposed for several hours to strong sun-heat, the water may be warmed by contact with it, and so exert a heating effect. On the other hand, when the sand has been uncovered by night, chilled by radiation, it may cool the water passing over it, or at least not raise its temperature. This hypothesis explains all the phenomena which we have observed as yet, and is supported by a considerable number of experiments; but Mr Peddie and I are about to commence a critical research to test its applicability, and also to investigate the variations produced by the currents in the quarry, the direction of the wind, and other causes.

I have to thank Mr Peddie, Mr H. N. Dickson, and Mr Lindsay of the University Physical Laboratory, Mr T. Morton Ritchie, B.Sc., Mr H. J. Gifford, and Mr W. A. P. Tait, for their valuable and self-denying assistance in making the serial observations described in this paper.

8. On the Isothermals and Adiabatics of Water near the Maximum Density Point. By Mr W. Peddie. Communicated by Professor Crum Brown.

The state of water, as regards pressure, volume, temperature, entropy, and energy, may be represented by surfaces in a number of ways, depending upon which of the properties we choose to have their numerical values measured off along the axes to which the surface is referred. The surface most suited for the consideration of the forms of the isothermals and adiabatics is that one the co-ordinates of each point of which represent pressure, volume, and temperature. The nature of this surface as constructed for water, and some of its peculiar features, were first studied by Professor James Thomson, and described by him in a communication made to this Society. Designating pressure, volume, and temperature by the letters p, v, t, the isothermals are the projections upon the plane (p, v) of the lines of intersection of planes of constant temperature with the surface. The adiabatics are the projections, upon the same plane of curves laid down upon the surface, such that, as the substance passes from one state to another as represented by points on the curve, it does so without absorption or emission of heat. The actual curve upon the surface may be termed the complete adiabatic. The chief features of the projection of the surface upon the plane (p, t) are three curves, which separate the regions representing the liquid, solid, and gaseous states. These three curves meet in a point, which Professor J. Thomson terms the triple point. If we measure pressure downwards and temperature to the right, the curve separating the liquid and gaseous regions slopes downwards from this point towards the right. The curve separating the solid and gaseous regions slopes upwards towards the left, making a greater angle with the t axis; while the other curve slopes downwards towards the left, and is very much steeper. The maximum-density curve slopes downwards to the left, but is not nearly so steep as the liquid solid curve which it meets at a point corresponding to a pressure of nearly three tons weight per square inch. It also meets the liquid-gaseous curve. Inside the triangular region so bounded the substance is liquid, and the quantity $\frac{dp}{dt}$ has a negative value.

For the liquid condition outside this region $\frac{dp}{dt}$ is positive. Hence, from the third thermodynamical relation, we find that in this triangular region the adiabatics slope downwards towards the left for increased pressure; while in the other region they slope downwards towards the right. So if we take a portion of the substance in a state corresponding to a point in the region where $\frac{dp}{dt}$ is negative, and allow it to expand adiabatically, its temperature rises. From calculations based upon the first and third thermodynamical relations, it seems that the slope of the adiabatics in this region is not so steep as the slope of the maximum-density curve. Hence we have adiabatics meeting this curve. But no such adiabatic can pass into the region where $\frac{dp}{dt}$ has a positive value, since the maximum-density curve slopes upwards toward the right. It must be determined by experiment then, whether the adiabatic coincides with this curve after meeting it, or if it re-enters the original region, its slope having become steeper. In either case we can have two adiabatics intersecting; that is, at a given temperature, volume, and pressure, we may have water near the maximum-density point, in at least two states differing in the amount of intrinsic energy possessed. If the adiabatics coincide with the maximum-density curve, we may have an infinite number of such states.

Now consider a portion of the substance in a state represented by a point in the region when $\frac{dp}{dt}$ is positive. On adiabatic expansion the temperature falls until the maximum-density curve is reached. After this, the temperature rises. Hence there is a point of minimum temperature upon the adiabatic. This point must be looked upon as one in which two adiabatics meet. Probably the course of each adiabatic meeting in one point on the curve (*i.e.*, the adiabatics whose previous courses have been in the region of negative and positive values for $\frac{dp}{dt}$ respectively), is different on further expansion. The amount of intrinsic energy possessed, determines which region the course will pass into on adiabatic compression from such a point. This is equivalent to

saying that lines so meeting are different adiabatics,—not branches of the same one.

As Mr Rücker (*Proc. Roy. Soc.*, vol. xxii.) has pointed out, it is possible that there may be a point of maximum temperature on the adiabatics within the region where $\frac{dp}{dt}$ is negative, for the substance is rising in temperature, while doing work by its expansion. This must be determined by experiment.

In the surface referred to above, there are three cylindrical regions, the projections of which on the plane (p, t) give the three curves already mentioned as separating the regions which represent the three different states. The triple point line is the line of intersection of these surfaces. Mr Rücker shows that, along the triple point line, and along all other isothermals in these cylindrical regions, the adiabatics coincide for some distance with the isothermals. He gives formulæ for determining the distances for which they coincide. Consider portions of the substance in the three different conditions, such that the state of the mixture is represented by a point on the triple-point line. If there is enough steam to just melt all the ice, the adiabatic and isothermal will coincide all along the triple-point line in the direction of lessening volume. If not, then the adiabatic will enter the liquid-solid surface. If more than enough, then it will enter the liquid-gaseous surface. On expansion, the lines will only coincide until all the water disappears, when the adiabatic will enter the solid-gaseous surface.

If with Professor J. Thomson we consider that portion of an isothermal where change of state occurs to be curved in the plane (p, v), so as to have parts corresponding to unstable conditions, there must always be more unstable conditions along an isothermal in the region separating the liquid and gaseous states than in the other two similar regions; or else there are more such unstable conditions in that region near the triple point line than at a distance from it.

PROCEEDINGS

OF THE

ROYAL SOCIETY OF EDINBURGH.

VOL. XII. 1883-84. No. 118.

Monday, 21st July 1884—continued.

The President gave a short Review of the Session, and added some closing Remarks as follows:—

The President said—This session of the Royal Society, not the least interesting or remarkable of the series, is now about to close. I have been furnished with a statement of the papers which have been read, which exhibits a creditable amount of industry as well as of ability among its members. It seems that of these 16 were in Natural Philosophy, 15 in Mathematics, 6 in Geology, 2 in Chemistry, 6 in Mineralogy, 6 on Meteorology, 2 in Spectroscopic Astronomy, 4 in Natural History, 5 on Botany, 5 in Physiology, 1 on Language, 2 on History and Antiquities, 2 on Anthropology, and 5 on Political Economy.

We have sustained some severe losses by death in the course of the Session. Two very celebrated men, whom we had the honour to number among the Foreign Honorary Fellows of the Society, died within a few weeks of each other—M. Dumas, the Perpetual Secretary of the French Academy of Sciences, having died on the 4th of April 1884; and M. Adolphe Wurtz, his friend and fellow-labourer, who pronounced a funeral oration on his death, having himself died on the 12th of May. Both these distinguished men were renowned throughout Europe for the invaluable contributions they had made to Chemical Science, and specially to that branch of it known as Organic Chemistry, in regard to which M. Dumas may be said to have initiated a new departure. He was born in 1800

in Genoa, and had therefore at his death reached the patriarchal age of 84. The value of his services during that long life to the cause to which it was devoted it is impossible to over-estimate. Similar honour is due to M. Wurtz, not only for his valuable labours in the same branch of Chemical Science, but from his numberless publications and discoveries within the whole circle of chemical knowledgef "It was his good fortune," says M. Friedel, in a funeral address, "as rare as well-merited, that in the midst of such a multitude of different investigations, he never saw one of his results questioned.' He was at the time of his death the designated successor of Dumas as Perpetual Secretary of the Academy of Sciences, which had long been an object of his ambition.

Among ourselves, we have lost some very eminent and familiar names, to which, on the present occasion, I cannot do more than allude. They will be duly commemorated afterwards. At the head of the list stands that of the late Duke of Buccleuch. I have individually taken another opportunity of expressing my appreciation and respect for the memory of that distinguished man, to whom Scotland lies under a heavy debt of obligation, and who will long be remembered throughout its length and breadth as one of its most illustrious benefactors. Even had he not possessed these distinguished titles to our grateful remembrance, the fact that he was the lineal representative of the first President of the Society would have given him a claim on our interest. The three other names on the list furnished to me were personal friends of my own, two of them school-fellows whom I had known from boyhood.

The first is that of Professor John Hutton Balfour, who was a Fellow of the Royal Society for fifty years, a Professor of Botany in the University of Edinburgh for thirty-four years, and Secretary of this Society for nineteen years. It is needless for me to speak to you, who knew him so well, of his kindly genial manner, his devotion to scientific pursuits, which began with his boyish days, and never quitted him during his long and useful life; and the clear discerning capacity, which enabled him to attain and retain the confidence of all who came in contact with him. Nor need I attempt to recount the valuable services which he rendered to the progress of that branch of science to which his life was chiefly devoted.

The second name is that of Allen Thomson. He too was a school-

fellow, and a man of very varied accomplishment, and of rare mental quality. Perhaps with a harder grain of fibre he might have attained more general fame, for he was singularly unassuming and gentle, not from want of intellectual force, but from the balance of a refined nature. But he was especially adapted for the prosecution of exact science by the clear lucidity of his thoughts, and the quiet impartiality of his judgment. As a companion, he was charming, as he had rich resources on which to draw, and a delightful vein of cheerful humour in which all who knew him rejoiced.

The last name furnished to me is that of one who well deserves to be commemorated here. It is that of the well-known Provost of Leith, Mr Lindsay. I am glad of this opportunity of expressing not only my sense of the benefits which his labours have conferred on the public, but my own individual feeling of obligation for friendly co-operation in important public affairs. The Police Act which bears his name, and his exertions in which have earned the gratitude of the public, was not indeed the last word on the sanitary legislation for our crowded towns. But it was the most important contribution towards it of our day, and I doubt, but for Mr Lindsay's help, it might never have been obtained. I had found on previous attempts that the opinions of the different burghs were so little in unison, that it was almost impossible to hope to adjust them within the compass of a Session of Parliament. But in reply to an application by Mr Lindsay made to myself as Lord Advocate at the time, to attempt to legislate in this important matter, I said that if he could obtain a reasonable acquiescence from the burghs in a general measure, I should be glad to aid in having it passed into law. Mr Lindsay accepted the proposal, and fulfilled his task with an amount of ability, tact, and patience which did him infinite credit, and deservedly earned for him the distinction which they yielded him.

The year has been otherwise memorable in more than one respect. We entered our second century; but on that subject I sufficiently enlarged on a recent occasion. It was also distinguished by the brilliant and most successful celebration of the Tercentenary of the University of Edinburgh. We had, during the celebration week, the great and rare satisfaction of having papers read to us by two of the Honorary Fellows of the Society—one by Dr Helmholtz of Berlin, who has gained a European reputation by his discoveries in

physics; and Professor Cremona of Rome, whose work on the Theory of Projection has met with great celebrity, and has been translated into many European languages. The Society had also the pleasure of hearing an address on Cosmic Dust from the Abbé Renard, who is not a Fellow of the Royal Society, but is known to us by his contributions to the records of the "Challenger" Expedition.

I have now only to express the hope that the Fellows may meet at the commencement of next Session, recruited for fresh exertions.

In connection with the Tercentenary celebration, I ought to mention that the Council did me the honour to appoint me as their delegate to represent the Society on that occasion. To my great regret, I was unable from the state of my health to attend the celebration, and our Secretary, Professor Tait, was appointed in my place. In the course of the discharge of the duty thus devolved on him, he presented a Latin Address from the Royal Society to the University, the terms of which were furnished by our Librarian Mr Gordon, and are as follows:—

AMPLISSIMO CANCELLARIO, RECTORI MAGNIFICO, DOCTISSIMOQUE SENATUI UNIVERSITATIS EDINENSIS.

VIRI ILLUSTRISSIMI—Societas Regia Edinensis commemorationem tercentenariam Universitatis Jacobi Sexti, Scotorum Regis, concelebrare et ornare vult. Etenim Societas Regia est filia Universitatis vestræ, cui suavissimo commercio et sanctissimâ necessitudine devincta est. Quam multi philosophi, Universitatis Senatores, pars magna sunt et fuerunt rerum a Societate gestarum.

Hoc die solemni memoriam magnorum virorum Academicorum renovare juvat, et tanquam Jacobi Sexti antecessor, Macbethus, obstupuit prolepticâ visione seriei regum Scotiæ futurorum, sic sed retrospectu contemplamur hodie illos sceptriferos scientiæ principes, Senatores Universitatis, qui ab urnis suis adhuc intellectum humanum regunt. En GREGORIUS, inventor telescopii reflexione agentis;—MACLAURINUS qui sublimiores res cosmicas illustravit, fluxum refluxumque maris, solis vias, lunæque labores;—ROBISONUS et FORBESIUS, ambo Secretarii Societatis Regiæ, alter expositor encyclopædicus totius corporis philosophiæ naturalis, alter novâ theoriâ de molibus conglaciatis clarissimus;—MONROI, anatomici celeberrimi, quorum Primus conditor Infirmarii, Secundus Anatomici

Musei vestri conditor;—Blackius, fundator chemiæ hodiernæ;—Cullenus originator pathologiæ philosophicæ, qui rationales methodos inanibus placitis scholasticis substituens, omnes medicos sui sæculi longe exsuperavit;—Jacobus Gregorius qui de arte medicâ scripsit latinitate elegantiori quam quâ utebantur Romani medici;—Carolus Bellius in æternum memorabilis, qui primus loca modosque functionum nervorum demonstravit;—Goodsirus, anatomicus nulli sui sæculi secundus, qui existentiam et structuram novorum animalium marinorum et parasiticorum indicavit, auctor et creator cellularis theoriæ, et ejus applicationis ad pathologiam et morphologiam transcendentalem;—Christisonus qui primus vim certorum toxicorum et medicamentorum suo periculo expertus est; quo nec ulla aetas nec civitas nostra unquam peritiorem aut feliciorem in tuenda et restituenda sanitate vidit;—Listerus conditor antisepticæ chirurgiæ, novæ et efficacioris methodi medendi;—Brewsterus et Leslæus, alter patefaciendo leges lucis, alter leges caloris celeberrimus;—Robertsonus, illustris fundator et pater Regiæ nostræ Societatis, qui in immortalibus historiis magnas revolutiones sociales et religiosas gentium facundissime enarravit et elucidavit;—Stewartus qui eloquentiâ antiquâ philosophiam Scoticam exposuit, et juvenibus nobilibus, postea imperio Britannico præfuturis, inculcavit principia renuntiationis et virtutis, atque responsibilitates libertati conjunctas;—Hamiltonius qui logicam Aristoteliam magnis augmentis ditavit, et novum splendorem philosophiæ Scoticæ addidit;—Chalmersius, orator, qui perfervidâ et excelsâ eloquentiâ atque administrativâ sapientiâ patriam suam ad altiorem statum religiosum, moralem et politicum sublevare enitebatur, semper urgens et incendens sublimem devotionem humanarum energiarum ad assequendas meliores et maturiores formas cujusdam perfectionis in longinquitate splendentis et evanescentis; philosophus etiam, qui præsentiam Dei in rerum naturâ, majestatem conscientiæ in homine demonstravit;—Wilsonus, vicissim grandis et solemnis, lætus et facetus, nunc miserationem seu pathos movens, nunc salibus Horatii vitia et stultitias insectans, nunc tenerâ sensibilitate Virgilii magnificentiam naturæ depingens, qui veluti prisci philosophi præcepta sua perpetuo carmine tradere gaudentes, poetico afflatu incensus tanto splendore imaginationis disseruit de affectionibus, voluntate, et conscientiâ, ut videretur niti,

analysi reconditâ rejectâ, auditores ad nobiles actiones et excelsas ideas summopere incitare; AYTOUNUS, quo nullus magis Musis patriae suae dilectus,—nihil quod ille cecinit de heroibus Scotiæ delebit ætas.

Satis habeatur dicere vos, viri illustrissimi, ab antecessoribus vestris minime abesse, optime de litteris, scientia et artibus meritos. Conjungentes itaque gloriam praeteritorum saeculorum ad splendidum progressum praesentis temporis, ampliore scientiarum curriculo, amplioribus aedificiis fruentis, pergatis rerum patefacere causas, ordinem et connexionem, resolventes problemata, et communicantes inventa quae attinent ad hominem, regnaque naturae varia,

Terrasque, tractusque maris, coelumque profundum.

Verum enimvero nunquam et nusquam gloria medicinæ magis floruit quam apud vestram Universitatem. Quot viri a vobis arte medendi instructi mortalibus ægris ministrant intra et extra Garamantas et Indos, ubi flumina Novi Mundi per cataractas stupendiores cataractis Nili ad Oceanum Atlanticum properant, et ubi insulæ terris continentibus æquales surgunt e Mari Australi. Quæ regio vestri non plena laboris?

Denique vestrâ Universitate semper strenue statuente eradicare et delere idola tribûs, specûs, fori et theatri, olim a Cancellario philosophico Jacobi Sexti reprobata, atque semper in magnis artibus et disciplinis colendis τὸ θεῖον καὶ τὸ ἀεί assequi enitente, fundamenta vestræ philosophiæ posita sunt non solum in cognitionibus a priori sed etiam in experientiâ; et fundamenta vestræ ethicæ doctrinæ non solum in utilitate, vel consuetudine, vel hominum pactis et conventionibus, sed magis in quodam sensu seu facultate regali, ut Platonice loquamur, nobis divinitus insitâ.

Comprecamur ut omnia vobis fausta et felicia eveniant, utque ita de scientiis, de litteris, de patriâ et de genere humano, ut meriti estis, in posterum magis atque magis mereamini.

Nomine et Auctoritate Societatis Regiæ Edinensis,

MONCREIFF, *Praeses.*
P. G. TAIT, *a Secretis.*

XV CAL. MAIAS, A.D. MDCCCLXXXIV.

An Analysis of the Principles of Economics. By Patrick Geddes.

(Read 17th March, 7th April, 16th June, 7th July 1884).

Introduction.

§ 1. In a paper * read nearly three years ago to this Society, I have attempted

(1) To review the existing state of statistics ;

(2) To define the nature of the subject, and its relation to history and the sciences ;

(3) Broadly to group and co-ordinate the whole body of existing and possible statistics, in relation to the respective statistical sciences ; and

(4) In accordance with the preliminary sciences to frame a classification embracing all existing and possible sociological statistics. Moreover,

(5) This was shown to involve, or rather actually to constitute, an aspect of the pressing problem of the systematisation of the literature of economics, of which

(6) The existing schools were briefly criticised ;

(7) The relation of the conceptions of scientific economics to practical economics was outlined ;

(8) As also their relation to ethics.

The present paper proposes to deal with more attractive aspects of economic science, and although inevitably to some extent also critical, is primarily of systematic and constructive aim.

§ 2. In the domain of all the studies which directly concern man —in biology and psychology, in ethics, politics, and economics alike—it has often been pointed out how theoretic conceptions are subtly, instinctively, almost inextricably interwoven with practical considerations. Economic literature is especially unfortunate in this respect ; in many authors hardly a sentence is without this double effect. To eliminate then, and reserve for separate subse-

* "On the Classification of Statistics and its Results," *Proc. Roy. Soc. Edin.*, 1881 ; also published separately by A. & C. Black, Edinburgh.

quent criticism, all practical considerations—to distinguish doctrine from practice, to separate principle from precept, and construct science apart from art—is the first aim of the present inquiry. Precisely as biology underlies medicine, and astronomy navigation, so sound practical economics can only be profitably attempted after sound scientific conceptions have been attained.

§ 3. The attainment of scientific principles being aimed at, the scientific method, and the scientific method alone, must be used. This involves a further, a sterner, and a far more difficult assay of economic literature than the preceding, which aimed exclusively at the removal of irrelevant practical matter. The influence of other extra-scientific conceptions, theological or metaphysical, optimistic or pessimistic, has also to be guarded against.

§ 4. Having then successively eliminated as irrelevant to our present purpose the disturbing elements above referred to, what strictly scientific matter remains? Much; yet this is in such a form as to demand a new analysis. For this, as in the preceding paper on statistics, two postulates are required—(1) the classification of the sciences, and (2) the main conceptions of each—the comparatively simple conceptions of physics preceding those of biology; those of biology being followed by those of psychology, and these again by sociology. The elimination of practical and of philosophical considerations does not then suffice. New difficulties were in the first place shown * to depend not only upon the profound disagreement as to scope and method of the subject, but as to its very nature, some claiming it "to be a logical science, others a mathematical, others a physical, others a biological, others a psychological, others a social, and others an ethical science; while some hold it to belong partly to one of these sciences and partly to another." Yet others, as if the wealth they are concerned with were not material, and the population of which they discuss the laws did not consist of living organisms, practically isolate it altogether from the sciences, even those of matter and life. The economist of literary or legal training assumes that subtle verbal definition expanded under the rules of formal logic will create a rigid, universal system. The mathematician upholds the "statistical method," or the expression of economic laws by algebra and the calculus. But the economist of more practical

* *Classification of Statistics*, p. 26.

and concrete tendencies interests himself as exclusively in "material wealth—its production, distribution, and consumption"; giving but scanty consideration to the nature and wants of the community for, and by which, this wealth is produced, distributed, and consumed. Most economists, however, are so far biologists as to recognise the physiological laws made prominent by Malthus. Psychologists and moralists, in insisting upon the estimation of pleasures and pains, or the analysis of mind and motive, have had no small influence upon economic theory; the historian has now entered the fray, and urges weighty claims to predominance; so too does the anthropologist; in short, it has been attempted to constitute the economic science by the aid of almost every possible mode and department of scientific inquiry, and no better evidence of failure can be imagined than is afforded by the claims of each of these inco-ordinated systems to exclusive success.

§ 5. Yet we are bound to assume the applicability of the sciences, and seeing that all have been by turns applied, how is the "notorious discord and sterility of modern economics" * to be explained? There are two main reasons for it—first, that the application of the sciences has not been systematic or in any way co-ordinated; secondly, that although applied, their application has been in almost all cases imperfect or faulty. The "statistical method" has been already criticised, and the few applications of higher mathematics yet made will not at present be discussed; but passing to physics, it will at once be evident to any reader, however little versed in science, that the discussions or definitions of the nature of "material wealth," of "intrinsic value," and the like, which are to be found at the outset of almost every economic treatise, remain at best in precisely the state in which Smith found them, and are wholly uninfluenced by modern physics. In biology too,—while the law of reproduction discussed by Malthus has become in the hands of Darwin the foundation-stone of that theory of evolution by natural selection, which has not only revolutionised modern biology, and with it our views of the origin, nature, and destiny of man, but has shed new and brilliant light upon the special sciences which concern him, anthropology, philology,

* Ingram "On the Present Position, &c., of Pol. Econ.," *Brit. Ass. Report*, 1878.

psychology, and ethics,—the economist alone remains behind, and although long ago armed with the purely biological ideas of competition and co-operation, delays to modernise his theories by the aid of the new learning, and treats them as if they were independent of such general conceptions of struggle for existence, of functional differentiation and change, of polymorphism, and the like, of which they are really special cases.

§ 6. We see, too, that theories of the mental and moral nature of man hold a large place in the constructive attempts of many economists, yet probably no one will seriously maintain that these extensive psychological postulates have much in common with any school of psychology now extant. Nor do the ordinary economic postulates as to the structure of society and the origin of its institutions contain much which Mr Spencer, Mr Tylor, or Sir Henry Maine would recognise as pertaining to modern sociology, but rather exhibit a closer affinity (suggestive of direct descent) with the "Contrat Social."

§ 7. Enough, then, has probably been said to show that even the economic systematists who seek to apply scientific conceptions at all are unfortunately provided for the most part with archaic or incomplete ones, when indeed they are not wholly erroneous; and political economy is thus seen to present in a marked degree that lagging behind the general advance of knowledge which not unfrequently occurs even in the ranks of the preliminary sciences—witness the obsolete chemical notation conserved by mineralogists.

§ 8. Political economy must therefore be treated as a crude science, standing to sociology much as the psychology of the last century to that now in process of evolution. Criticism of such provisional syntheses must be (1) appreciative of them as embryonic stages of true science, and for their historical services; but (2) destructive where they claim vitality and impede progress. The former is a branch of history proper, the latter of what we may call intellectual palæontology. This criticism by means of the preliminary sciences is therefore really conservative, since it affords a touchstone for assaying the whole literature of the subject, sentence by sentence, if need be.

Even though the reader may feel contented that the particular system to which he happens to have been trained or attached is

exhaustive and satisfactory, its usefulness will really be to him none the less, since the synthesis which, through this analysis, we shall ultimately reach must coincide with his own,—thus constituting a brilliant independent verification such as is eagerly sought for in science,—and so establishing his position to the exclusion of all others.

§ 9. At whatever labour, then, the economist must no longer shrink from acquainting himself with the preliminary sciences; the common objection that he "finds it laborious," or that he "cannot hope to become a specialist," and the like, notwithstanding. But fortunately such alarm is groundless, for no specialist's knowledge is required. It will be found in the sequel, that just as the most elementary, if clear, knowledge of mathematics, scarcely extending in algebra beyond simple equations, nor in geometry beyond the construction of rectangles and curves, is shown in statistical treatises to give a new precision and clearness to conceptions of economic quantity; so a similarly rudimentary, if real, knowledge of physics and physiology—of the doctrines of the permanence of matter through transformation, of conservation and dissipation of energy, and of the functions of living organisms—will here serve for a commencement. Nor will more be postulated in the present work.

The plan of the undertaking will now be readily understood; it is, in short, once more to prepare for the construction of a "system of economics"—not, however, by means of new definitions and old dialectic, nor by the deductive application of a few principles taken at random from an early state of some single science—but in harmony with the organic whole of the preliminary sciences; using, as far as may be, such materials as after due refining economic literature may afford; thereafter proceeding as far as possible by investigation. It is necessary then, in the first place, to collect and arrange the materials for such a system by successively extricating from the vast mass of too discordant economic literature, and by observing as far as possible in actual society—first, the most important facts and generalisations of physical and chemical nature; next, those essentially biological and psychological; finally, those distinctively sociological—uniting this task of constructive criticism and new observation with such application of those respective sciences as may be possible. Thus principles of economics serviceable for the

subsequent construction of systematic economics can be obtained and tested; and to point out the road which may lead to the elucidation of such principles—without any pretence at exhaustive treatment of detail—is the aim of this paper. The existing economic literature, then, will henceforth be regarded as a storehouse of ideas of all kinds and ages, which, in so far as scientific, we have to disentangle and arrange on the plan above outlined into bodies of principles, dealing with each successive aspect of the subject, physical, biological, psychological, and social, these forming separate chapters, each accompanied by a summary, while the appreciation of the history of economics will be postponed. The inquiry as to the logical method or grammar of economics, and the mathematical principles involved in its treatment, instead of forming the subject of an initial dissertation, will be relegated to a final appendix also of partially historical character.

§ 10. But the economist, even if not refusing the systematic application of science above proposed, will urge that economics must not only be pure but applied, not only scientific but practical. Assuredly so; for while eliminating as irrelevant any admixture of practical considerations with the purely scientific portion of the subject, it will yet be attempted, in an appendix to each chapter, though of course only in the most brief and general way, to indicate the possible lines of modification of each set of factors, whether such modification has been effected or attempted in past or present time, proposed by any of the various schools of practical economists, or suggested by scientific knowledge.

§ 11. The plan proposed is thus easily applicable to the wants of either specialist or generaliser, whether of scientific or practical bias; for the chapters may thus be successively read for the doctrine, and their respective appendices thereafter for the derived practice. And when the work is completed, while those especially familiar with the preliminary sciences will doubtless prefer the ascending order from physics onwards, the student whose interests lie rather in the supreme social and practical aspects of the subject, will without much inconvenience take the chapters and appendices in the reverse or descending order.

§ 12. But even then we have no system of economics. True, nor has any system yet existed, the innumerable so-called systems

being, as we have seen, complex mixtures of ideas of every possible order, which, from the present point of view, are to be regarded as material to be disentangled and rearranged on the plan above outlined into bodies of principles dealing with each successive aspect of the subject. Those principles once extricated, however, we obtain a key to the mode of construction of these systems, and an explanation of their incompleteness—each school, as was already pointed out, having grasped principles chiefly referable to one order only, and having used these to the practical exclusion of principles belonging to other orders. Hence such efforts as to restrict the domain of economics to questions of statistics, value, or exchange; and the attempt thus to solve all problems is obviously incomplete. Similarly, the restriction of the subject to material wealth, without consideration of the organisms of which the occupations, rate of reproduction, mode of competition, &c., furnish biologico-economic principles. So with the investigation of biological principles without heed of the next order of factors—the psychological principles—or the very frequent attempts at completing a system, by the aid indeed of biological and psychological considerations, but without passing from the study of the individual to that of the higher unit—the society—with which the sociological principles are alone concerned. These are all examples of an attempt on the part of each preliminary science to annex the province of the succeeding one, an error which of necessity vitiates the system thus obtained. To this intrusion of each preliminary science upon the domain of its ascending successor, the term "*materialism*," though generally restricted to the attempt to reduce all sociology and morals to biology and physics, has with great advantage been sometimes extended.

§ 13. The existing systems of economics are not only vitiated by this error of some form of "materialism," but also largely by the converse and if possible more serious error, that of attempting to make any one science do duty for those which underlie it,—which may conveniently be termed "*transcendentalism*." The attempts at system vitiated through the error of "materialism," which we have just been criticising, have largely indeed been due to an even earlier prevalence of "transcendentalism." The man of moral bias, in attempting to construct a perfectly moral theory of economics without full and constant reference to the facts of exchange, of production,

of population, of their wants, and of the existing society,—which furnish the principles underlying any moral theory,—has long since brought the whole subject of morals into disgrace among economists, with the lamentable yet not unnatural result that any one attempting to introduce ethical considerations, even in their proper place, is apt to be scouted as a "sentimentalist." Again, the economist to whom the society is of paramount interest, frequently ignores its individual components, and so on. So strong, indeed, is this tendency to transcendentalism, that the class of principles with which we shall commence our ascending survey—the physical—has been the very last to secure a hearing. In short, each of the succeeding chapters, physical, biological, &c., looked at alone, is a systematised materialism to its successors, and a transcendentalism to those which precede it. Hence the need for an ultimate synthesis, which must aim at reconciling all these different points of view.

§ 14. The synthesis to be attempted, then, must aim not only at balancing the claims of all these principles without that excessive or defective insistance upon one order of them which constitutes materialism or transcendentalism, but at interweaving them into a lasting whole. The postponement of the construction of a system (imperfectly foreshadowed, however, in the *Classification of Statistics*) to the present task—the discussion of principle—is thus necessitated; hence the plan of the present work.

Chapter I.—Physical Principles.

§ 15. *General Enunciation of the Problem.*—Passing over the discussion of the mathematical aspects of economic phenomena to the consideration of their concrete physical aspect, we are not simply concerned with the abstract theory of statistics or of exchange, but have to investigate the concrete economic facts; and these not only in their quantitative, but also in their qualitative relations. The apparatus and the processes of social activity have to be observed and classified with an equal eye towards minuteness of detail and extent of generalisation; they must, moreover, be expressed in terms of physical science. For as the physical physiologist has long since definitely undertaken the task of explaining the mechanism of the individual organism in terms of chemistry and physics; or as the

physical geologist not only observes the form and changes of the earth's crust, but explains them by the aid of the same sciences; so precisely must the physical economist deal with those phenomena of the visible universe which are specially allotted to him. From the present point of view we must constantly bear in mind that all these phenomena are alike material—that all the changes which we observe, whether in the earth's crust, in organisms, or in the interaction of organisms with their environment (an inquiry within which indeed the economic operations of mankind are not only recent but comparatively small), are alike expressible in terms of chemistry and mechanics. Social phenomena are to be viewed simply with regard to the matter and energy consumed or liberated, and physical economics is thus the study of certain forms of matter in motion.

§ 16. *Particular Enunciation of the Problem*—Leaving to later chapters those considerations of biological, psychological, sociological, and ethical scope, which are present or latent in almost every extant discussion of "material wealth," and endeavouring to dispense altogether with metaphysical thought and metaphorical expression, and postulating simply the elementary facts of physical science, and more especially those of the doctrine of energy, we may enter upon our inquiry. What is this "wealth," what is meant by its "production," its "distribution," its "consumption?" What are "land, labour, and capital?" What is this process of "exchange," and what is the meaning of "value?" What are "producers and consumers," and so on?

§ 17. *Qualitative Analysis.*—It is convenient to begin with the "producers and consumers." These indeed as organisms might at first sight seem only admissible when biological aspects of the subject are being discussed, but it has just been pointed out that the physiologist has already in great part interpreted their functions in terms of pure physics, and we are thus not merely entitled, but bound to include them in our present survey. They come before us, however, not in all their complex relations, afterwards to be discussed in the biological chapter, but simply as so many forms of mechanisms constructed from the matter of the earth's crust and worked by the energy of the sun—as so many species of automata called *Homo*, *Formica*, &c. Every such automaton is of course constantly wear-

ing out, and its energy running down—and this waste which its functions involve must be repaired by obtaining from the environment periodic supplies of new matter and energy. From the destructive forces of the environment it must similarly be protected; and so on. From the present standpoint then it is not merely analogous to, but identical with a mechanism; "producers" are those automata devoted to the acquisition of matter and energy from the environment; while all are "consumers," and in this aspect in wonderfully similar degree.

Without ignoring the historic services of the physiocratic school, the application of the conceptions of modern physics to economics may be fairly said to date from Professor Tait's discussion of the Sources of Energy in Nature, published about twenty years ago (see *North British Review*, vol. xl., also Balfour Stewart on *Heat*, &c.). The subject has been developed to some extent by other physicists, as Siemens, Thomson, &c., but seldom by economists, with the distinguished exception of Professor Stanley Jevons, whose investigations on the coal supply, and whose hypothesis of the correlation of sun spots and commercial crises, are both essentially from the present point of view.

Starting then from a given territory at given time, and enumerating the utilisable sources of matter and energy in the form given by Tait, and adopted in the *Classification of Statistics* (p. 13, table B), we may proceed to systematise the phenomena of production and consumption, and this is most conveniently done in diagrammatic form. Let us arrange these facts—which should of course aim at statistical precision—in a first column. (*Op. cit.* and fig. 3.)

After these we may further enumerate the sources of matter not used for the sake of its potential energy, but on account of its other properties (physical, chemical, &c.). This matter and energy are as yet mere raw material or potential products, and require development into ultimate products; the requisite processes of production having generally three stages—exploitation, manufacture, and movement, the last including transport and exchange; for exchange from our present point of view is simply part of the process of movement of the product from the place of production to that of consumption. That proportion of potential products (large in complex societies) which has to be converted into *apparatus* used in

the stages of development is conveniently termed *mediate products ;* and thus we have an exhaustive classification of all products whatever in its most generalised form. Finally, much premature dissipation and disintegration, termed loss, may occur at all stages of development and must be estimated for.* (*Op. cit.*, pp. 13 and 14.)

As has been already shown, such a table includes not only an account of the processes of transport and exchange, but of the facts of the equally relevant though less investigated subjects of exploitation and manufacture, commonly grouped under technology.

The standpoint being thus sufficiently explained, and the stages of production defined, it is obvious that our physical standpoint enables and compels us to inquire into their details. Were this an exhaustive treatise on physical economics, it should commence with a minute statistical survey of the sources of energy and of the processes of exploitation—agriculture, fisheries, mines, &c. It should include not only the classical quotations from Smith on pin-making and Babbage on the economy of manufactures, but a thorough survey of manufactures and of the vast appliances of modern transport by land and sea; it should summarise those investigations upon the phenomena of exchange, upon which so many economists entirely specialise themselves; it should also estimate the loss at all stages preceding consumption; at every stage, too, it should consider the mediate products and the producer-automata employed; and, finally, it should classify and estimate the ultimate products.

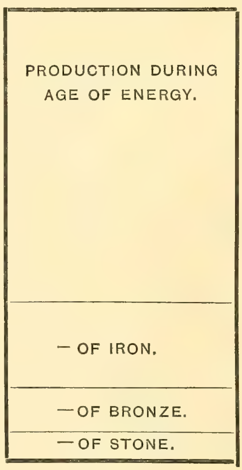


Fig. 1.

So far, our knowledge would be confined to a given place and time; but such statistics should be sought for all other places and times, these statistics piled up into history, and this history generalised and compared. Thus, we should investigate such a hypothetical graphic statistic as the accompanying; aim at approximately comparing, that is to say, the relative income of matter and energy

* These considerations are more fully developed in the *Classification of Statistics*, pp. 13, 14.

from Nature in the various ages of production—stone, bronze, iron—with which the archæologist (who is indeed essentially an historical economist) has done so much to acquaint us, and compare these with the result in our modern age of energy. The historic evolution of processes and products, both in their varying rates and details, and in aggregate, should further be discussed; for of the (derived) hypothetical historical curve (fig. 2) our fragmentary historical knowledge would enable us to approximately fix a few points.

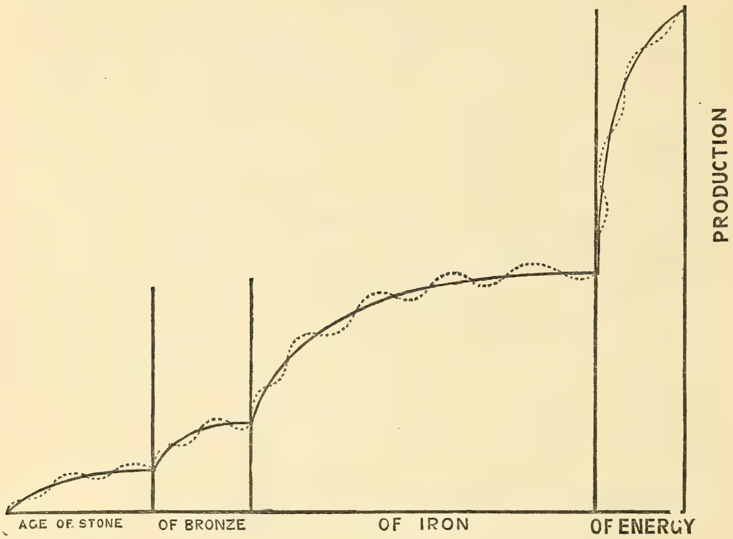


Fig. 2.

Such a curve could, of course, be precisely ascertained for some elements of recent production; and valuable conceptions, as, for instance, the "law of diminishing return," derived from it by mere inspection.

Similarly the specialisation of processes known as "division of labour," and the converse process of generalisation, or "concentration of labour," are more clearly intelligible. "Capital" is decomposed into the apparatus (mediate products), and energy employed in production. No elaborate discussion is needed to refer "money" to its place amidst the apparatus of movement, and so on.

But where is the novelty and what the utility of such an analysis, the economist may by this time naturally ask.

Such detailed studies are, of course, largely scattered through economic literature, nor does any one dispute their relevance. Such abundant extant investigations as those upon the phenomena of trade and money, or the vast historical labours which are specially due to the German school, furnish abundant partly co-ordinated material. The present aim is, however, to suggest how such positive results must be systematised and interpreted in terms of physics. And it must now be further shown that not only are our studies of economic processes, so far as consistent with fact, capable of physical expression, and (1) that this leads to greater systematisation—to greater precision of treatment in detail; but also (2) that this mode of treatment involves a considerable change in the conventional theoretic point of view; and (3) that it furnishes grounds for a systematisation of practical action.

§ 18. *Quantitative Analysis.*—The conception of the processes of production and consumption as one vast mechanical process; the view of society as a machine, in which all phenomena are interpreted as integration or disintegration of matter, with transformation or dissipation of energy, affords not only a generalisation of the widest, but a systematisation of the most thorough kind; nor is its applicability qualitative only. It is legitimate, nay inevitable, to apply the quantitative conceptions of physics—the modern measurements of matter and energy. Such and such quantity of matter is exploited, say a units; so much is lost in each process of production $(b+c+d)$; so much remains as ultimate product $(a-(b+c+d))$; after consumption so much of this becomes available for new exploitation as a waste product. Again, so many units of energy a are exploited; the processes of exploitation, transport, &c., cost so many units, say b; the remainder $(a-b)$ is the energy available. This idea is ex pressed by the upper portion of the diagram, fig. 3 (*q.v.*). The amount of energy and matter exploited during unit time is denoted by the first rectangle, and the quantity disintegrated and dissipated in the process by its upper dotted portion; the difference passes to the manufacturer, whose waste and expenditure of matter and energy are similarly denoted; the remainder, after again suffering deduction for the processes of movement, and the accompanying losses, represents the amount of ultimate product, of which the transitory and permanent portions are similarly estimable. Taking, for example,

our most important source of energy—coal; the complex problems of its ratio of exchange, and the causes of its fluctuation, of the

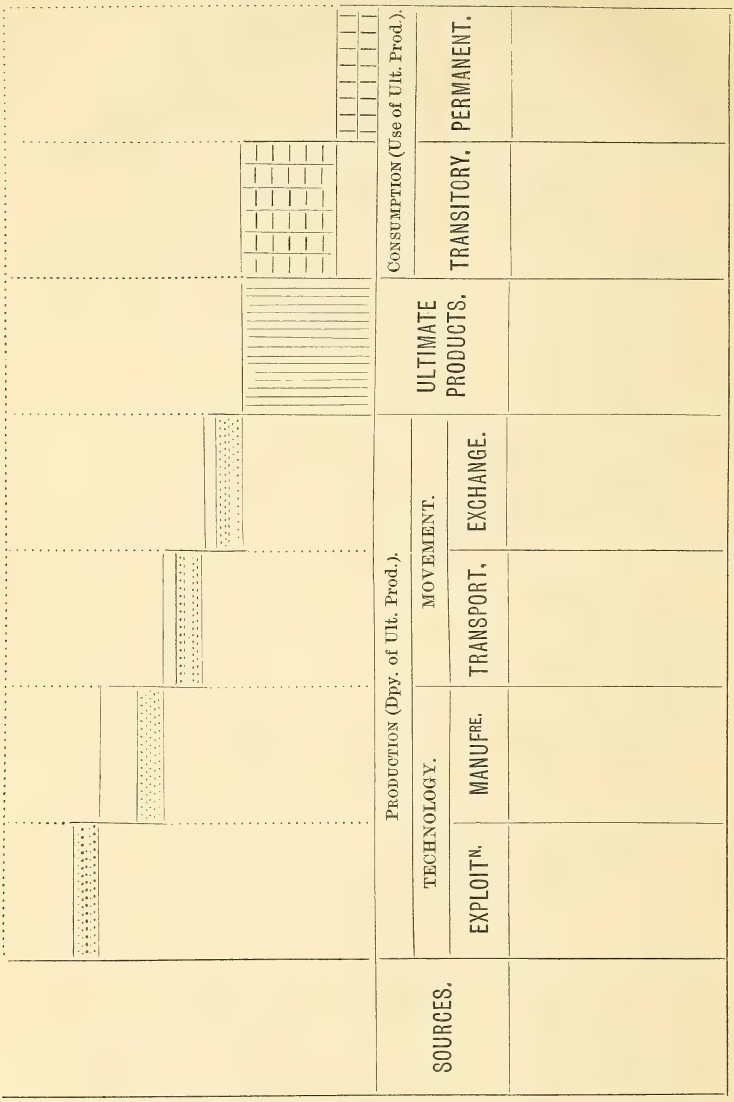


Fig. 3.—The lower portion of the diagram is intended to contain the details of production and consumption; the upper to record the changes of matter and energy in the process.

external and internal relations of the producer-automata, of the

apparatus and energy employed in its exploitation and movement—in short, of price, labour, capital, &c., and so on, have all to be discussed. Much of this is done in ordinary treatises—the primary and essential physical problem, however, remains (untouched by economists, save Mr Jevons almost alone)—that (1) of estimating the total quantity of energy stored at our disposal in this form per area of territory; (2) the gross and net quantity utilised per unit time; (3) the details of its utilisation and ultimate dissipation.

Thus physical precision can be approximately reached: measurement in terms of units of energy as well as of units of weight is practicable: and, this physical conception once introduced, its extenson to all processes must be attempted. For the treatment of this only one other consideration need be pointed out—the possibility of expressing the labour of the producer-automata, just as we do that of the ordinary machines with which they are so largely interchangeable: the horse-power of an engine is easily translatable into man-power—might, indeed, always have been so expressed; this granted, the conception of a *man-day* (of course averaging the same for labourers of a given community at given time, though vastly differing according to the age of energy) and its multiples (man-year—man-life) with the higher multiples of these can all be approximately stated. Producers and machines are, in short, not only interchangeable but commensurable.

Against the gross product of exploitation must be set the quantity of matter and energy expended in its production, together with the quantity wasted through the imperfection of our processes, plus all losses through other agencies. The gross product is expressed by the rectangle of exploitation in the upper table, the deduction for losses is indicated by the uppermost portion cut off from it, that for cost of production by the lower dotted portion, the remainder is the net product. Upon this the processes of manufacture and movement have to operate; and their cost and loss being similarly deducted, the remainder is the net amount of ultimate product.

In the hypothetical graphic statistic of the table, the net amount of ultimate product may seem unwarrantably small in proportion to the gross amount of potential product; this smallness is intended to suggest the vast losses of energy and matter, often many times exceeding the product, due to the imperfection of our processes.

This element, however, does not of course enter into the cost of production, which involves merely the apparatus, mediate products and energy actually expended, plus those losses by fire, &c., already mentioned. And thus, though the net quantity of ultimate product may be very small in relation to the gross quantity exploited, the process yields a profit so long as the sum of the rectangles representing the cost of production at each stage does not equal or exceed that representing ultimate products, and this surplus is in fact the *interest* paid by Nature upon the matter and energy expended upon her during the processes of production. The *rationale* of the partition of this surplus, and of the ultimate products generally, cannot be considered until after the psychological and social conditions, which so largely determine them, have been investigated; the actual facts of movement and position of ultimate products can of course be observed, and the physical economist then has means of measurement and comparison other than that afforded by money,—his units are really the metre and kilogram of the physicist,—and only when some quantitative data in these terms are approximately reached will those expressed in money be really capable of interpretation. And if space allowed, the difficulty of such statistical measurement of all the greater economic processes might be shown to be much more apparent than real. Many fragmentary investigations of this kind indeed already exist; thus we constantly find the mechanical energy of Britain described as the addition of so many million workers; suggestions, too, have constantly been made to estimate capital, or to express the ratio of exchange of products in terms of the labour they represent, and many other ideas emitted which await the systematic application of physical measurements.

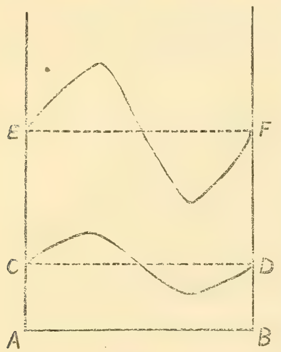


Fig. 4.

§ 19. *Quantity of Ultimate Products per unit time.*—The quantity of ultimate products obtained per unit time being known, the average store of wealth of the community, and even the details of partition are readily observed and denoted. Thus (fig. 4) the rectangle ABCD may denote the average wealth of a community at one time,

and ABEF at another, while the wave lines joining CD and EF respectively denote those deviations from the average partition, termed *riches* and *poverty.* But, as was pointed out in the preceding paragraph, though these phenomena can be observed, their explanation does not come within our present province.

§ 20. *Quantity of Ultimate Products per aggregate time. Synergy.*—The summation of the quantities of product in successive times, though seldom considered, must, notwithstanding, be attempted. Taking the year as our unit time, the quantity of production per lustrum, decade, generation, century, even per economic age, must all be inquired into, and the ultimate aspect, the highest generalisation of production, is that of the collective production of mankind—of the *Synergy of the Race*, with its material products, transitory and permanent.

§ 21. *Quality of Ultimate Products.*—The problem of classifying the ultimate products now arises. These are frequently arranged (1) according to their sources, or (2) according to the processes by which they are obtained, while (3) the only plan which really treats them as *ultimate* products at all, arranges them according to their relation to the consumers (these being, as already explained, from the present point of view mere automata needing fuel, shelter, covering, &c.). Ultimate products are thus commonly classified by economists, yet an important rectification is necessary.

The number of consumer-automata being definite per unit time, the quantity of ultimate products required per unit time ("*necessaries* of life"), fuel, shelter, &c., for their structural and functional maintenance is also perfectly definite and ascertainable. Without entering upon an elaborate yet practicable investigation of the details of this, it is evident that a criterion is furnished us by the durability of the automata in question. For, if these last the normal time, it is evident that the necessaries for normal maintenance cannot to any serious extent have been deficient. Thus we should expect *à priori* considerable definiteness of quality and quantity of ultimate products through all variations of space and time; yet rather the reverse seems observable. For a Russian, Norseman, and Scot, living in much the same geographical conditions and for much the same time, the quantity of ultimate products consumed per annum is enormously

different, being expressed in money values by a recent authority* as what we may take in round numbers as £7, £14, and £30 respectively. How is this to be accounted for?

The ordinary method of meeting the difficulty is to distinguish ultimate products into necessaries, comforts, and luxuries, and to account for differences in consumption, by assuming a greater amount of the latter. To give this scientific precision, we may first distinguish the ultimate products into a definite quantity of necessaries, plus a variable amount of *super-necessaries*, and then inquire what is the quantity and what the quality of the latter. The food consumed in these two places cannot vary much in quantity, the necessary fuel (proteids, fats, amyloids, water) must like be present in each case; how is the enormous difference in quality to be explained? If one represents necessary alone, the other represents necessary + super-necessary: the former replaces structure and maintains the energies; but the latter is only intelligible when we anticipate and borrow a conception from physical physiology: it is addressed to the stimulation of the sense organs, gustatory, visual, and tactile, of the consumer—represents so much *æsthesis.* The variable super-necessary must henceforth therefore be termed the æsthetic element, and ultimate products are accordingly analysed into their necessary and their æsthetic elements.

From the preceding discussion it is obvious that if population and duration of life be constant, all increase in ultimate products per unit time is expressible in terms of æsthesis, and it remains to investigate the relative amount of this.

It is commonly assumed by economists of all schools, that in production the necessary element enormously predominates—in any but the very poorest communities, however, this conclusion has no justification in observed fact. In the above case of Russian, Norseman, and Scot, even if we assume the consumption of the first as purely of necessaries, the element of æsthesis in the consumption of the last must be approximately (local differences in purchasing power being disregarded, especially as smallest for necessaries) measured by the difference in expenditure above mentioned, and must stand to the necessary element as say 3 to 1. So far, therefore, from calmly ignoring æsthetic considerations, a nearer approximation to

* Mulhall, *Balance Sheet of the World.*

the facts of production and consumption might actually have been reached by economic writers had they restricted themselves to these.

Thus, even for the physical study of production while the importance of the necessary element is fundamental, that of the æsthetic is superior. In any at all civilised community, in short, every ultimate product has visibly superadded its *æsthetic subfunction* of visual stimulus, and (without trespassing in any way upon the province of æsthetic criticism by considering its quality) the physical economist must estimate the details and cost of production of each of these two elements respectively. And when we add up the æsthetic subfunctions of all "necessary" ultimate products, and add to this the vast quantity of purely æsthetic products, we see how small the fundamental element of production has become in relation to the superior, and reach the paradoxical generalisation that production, though fundamentally for maintenance, is mainly for art.

§ 22. *Consumption.*—Passing to the study of the disintegration and dissipation of energy which we term consumption, we find that this takes place at variable rates. What disappears per unit time as food, clothing, &c., is termed transitory, what remains is relatively permanent. As the unit time is extended from day to year, and from year to generation and century, the transitory element of course increases at the expense of the permanent. And since the ultimate product newly produced + the store of permanent products constitute the quantity of wealth per given time, this is seen to be equally modifiable by the two independent variables of production and conservation. The old conceptions of domestic economy find here their place and use, and only require generalisation to be exhaustive. The term consumption is only fairly applicable to its transitory element, and should be superseded in its generalised sense by the homelier term of *use*.

§ 23. *Economy.*—Passing to the most highly generalised conception of use by extending space and time till we reach the synergy of the race (§ 20), the importance of the element of conservation becomes of ever-widening importance, for the accumulated wealth—and consequently the historic synergy—may be said to vary almost inversely as the transitory, and directly as the permanent elements of production.

§ 24. *Physical Aspects of Population.*—It might at first seem that all questions of population must be left to the biologist; yet a certain aspect of the subject must inevitably be taken here. For the processes of production not only machines but "producer automata" ("hands") were seen to be necessary; and the latter simply differ from the former in consuming ultimate products as fuel, &c. The portion of ultimate products thus consumed (which then return in fact to the category of mediate products, being hence often included under capital) varies per "hand" per unit time—and is accordingly known as the "standard of comfort." Increase or decrease of production (processes and standard of comfort being constant) must therefore be accompanied by proportional increase or decrease of producers, and hence the multiplication of population is seen to have a strictly physical aspect. In other words, the investment or withdrawal of capital in production involves a proportional stimulus, or check to population, and similarly with variations in processes or in standard of comfort.

Appendix to Chapter I.—Practical Physical Economics.

§ 25. *Practical Physical Economics.*—On the plan already outlined of investigating the practical aspect of our subject, we should inquire in what directions do all the various observed social changes tend? what modifications of them are consistent with physical law? and by the systematisation of these obtain our ideals or utopias: but it needs no detailed investigation to see that all changes of production and consumption tend either towards increase or diminution of their results per unit time (even maintenance of production tending strictly to the former), every movement of man upon the globe acting in one or other of these directions; hence alternative ideals of production appear at once, and admit of simple formulation into rules of practice:

$$\left.\begin{array}{l}\text{1. Maximise production}\\ \text{2. Minimise production}\end{array}\right\}\text{ of ultimate products per unit time;}$$

with subsequent similar rival ideals of consumption,

$$\left.\begin{array}{l}\text{(1) Maximise consumption}\\ \text{(2) Minimise consumption}\end{array}\right\}\text{ of ultimate products per unit time.}$$

§ 26. *Ideal of Production.*—We are called upon here to select between two alternative ideals, and without entering into any discussion of optimism or pessimism, we are compelled as practical economists to ignore the second, which leads of course to the negation of practical economics altogether. We have simply then to discuss the practical means of maximising production per unit time, though noting that every action in the community is ascertainably of one or other tendency.

§ 27. *Production.*—Starting from the estimate of the attainable sources of energy in nature, and from the scrutiny of the processes of technology and movement already outlined, our maxim leads directly to the organisation of production so as to maximise *ultimate* products. Improvements in exploitation, increase in manufacturing power, diminution of friction in transport, simplification of trade, are the four great heads of this process of which the endless details need not be here developed, especially as on the theory of conservation of energy all are reducible to the same unit of measurement. With respect to organisms this involves (1) a maximisation of their usefulness for production in every possible way besides the corresponding increase in their numbers.

§ 28. *Consumption.*—Passing to the maximisation of consumption per unit time, we see at once that this involves making all products transitory; minimising similarly implies making all permanent. Hence maximisation of permanent products has a reactionary diminutive effect on the producing population, just as the opposite—maximisation of transitory products—involves their indefinite increase.

In other words, the physical economist, desiring to increase not the population, but the wealth of nations,—instead of simply approving the continuous development of the existing industries, and attempting to increase average well-being by stimulating the exploitation, manufacture, or exchange, of the transitory products with which these mainly deal,—must advocate the proportional increase of permanent ultimate products, and organise industrial processes towards that ideal. We have thus reached the new paradox (*cf.* § 21) that the sphere of practical physical economics is to discuss the ways and means of increasing not so much bread, as Art.

Chapter II.—Biological Principles.

§ 29. Widely current in economic literature are conceptions which seem to have more or less biological character—one hears of "parasitism," of "competition," of "laws of population," of the "social organism," and even of its "circulatory," and "nutritive organs," and so on, besides many others which though not necessarily couched in current biological language, yet readily bear translation. It is here proposed to criticise and, to some extent, systematise this aspect of economics.

At starting, we meet the difficulty, that past economic literature necessarily shares the character of past literature in general, and more or less completely ignores physiological, zoological, and anthropological facts altogether. It is necessary to postulate the results of all these sub-sciences most clearly, and the biologist, avoiding misleading "comparisons between man and nature," must work forward from the actual living "man and his place in nature," without particular respect to the authority of any time-honoured theories of "human nature," or of the "economic man."

In passing from the physical to the biological aspects of economics, our producers and consumers are no longer regarded as automata, and generalised along with machines; but are looked on as specimens of a species of living organism, to be generalised with the rest of organic nature, terminating the greatest line of genealogical ascent, and supremely successful in the struggle for existence and domination, in virtue of peculiarly high evolution of the nervous system.

Our biological studies then commence with a knowledge of the statical aspects of Homo; with an organised census,* in which the quantity and quality of the population are carefully recorded: the

* The reader may at first suppose that it is here attempted to discuss questions essentially sociological under biology—but this "materialism" (*v.* § 12) will be carefully guarded against. All that concerns only the objective and bodily side of a man is purely biological; and this may be summed up for a number of men, looked at simply as a herd or mass, without leaving the field of pure biology. Sociology, on the other hand, concerns itself with individualities of a higher order:—with aggregates of men *integrated* into wholes for definite functions; as firm, bank, company, regiment, post office, and only considers the individual components in their relations to these. The census, then, is primarily biological, but also of course has sociological elements of high importance;—but these await separate and subsequent discussion.

observations of the biologist, and the anthropologist, of the registrar, census-taker and actuary, the hygienist and the educationist, are all organised into a vast body of knowledge—the statistics and generalisations of the new sub-science of "demography." *

But our survey must be not only statical but dynamical, not only structural but functional; how are we to approach this? Protoplasm undergoes incessant waste, and demands incessant repair, and it is this fact which underlies economic activities. However different in details, all the higher animals agree in obtaining the food needful for repairing the waste of their tissues, from their environment by the performance of muscular contractions co-ordinated by the nervous system. And this furnishes us with the widest definition of productive labour:—while the "sense of effort," the "pain," the "curse of labour" so much insisted on, is at most merely an accompaniment, incidental either to excessive exertion or defective adaptation to the task.

§ 30. *Evolution of Production.*—From the simple conception of animal production here laid down, we have to trace the evolution of modern industry; nor are the main steps numerous or difficult. The animal demands only ultimate products, and at first only *produces* food, accepting for shelter simply what the environment chances to afford. With increasing intelligence, shelters are next constructed: a bird's nest is as truly an ultimate economic product to its builders as a house to man. In the case of some the æsthetic subfunction begins to appear, and some animals, like the Australian bower-bird, even spend no little labour on purely æsthetic production. Stages of exploitation, manufactures, and movement are frequently more or less distinguishable; but all products as yet are ultimate. Mediate products, however, also tend to arise—like the roads and granaries of the ant, the engineering works of the beaver, or the stick and stone of the higher apes—from which to the rough flint implement of the palæolithic man the transition is easy. Given this implement, however, man becomes "a tool-using animal," and the evolution of ultimate products goes on apace. From this point the history of productive processes is being admirably traced by the combined labours of archæologists and historical economists. It is sufficient here to recall the origin and aspects of the producers.

* *Vide Classification of Statistics*, passim.

Beyond the primary economic differentiation involved by sex, all economic functions are at first united in each individual. As population increases, the advantage of numbers (the "simple co-operation" of economists) becomes felt; then slight variations of individual and circumstance lead to the repeated performance of some one function by particular individuals, the efficiency and rapidity of its performance then alike improve, and the advantages of *specialisation of function*, or "division of labour," become obvious, and tend to be continued and perpetuated. This differentiation once set up, it continues as long as circumstances render it advantageous or possible, and the complicated co-operation of the ant-hill or the city alike arises. These familiar considerations show that the "specialisation of functions" in *Formica* and the "division of labour" in Homo are not merely "analogies between man and nature"—interesting only to those who care to trace such com parisons,—but are absolutely identical.

§ 31. *Result of Specialisation of Function upon Organism.*—The differentiation of production leads then to the development of occupations, which, especially when perpetuated by heredity, are again seen to be of identical nature with those of the polymorphic indivi duals of the ant-hill. And all occupations are not *directly* concerned with production: some individuals specialise into the indirectly productive service of government; others leave productive operations on surrounding nature for the bodily care and service of their fellows; others, again, become unoccupied; and thus the three great classes of occupations (*Classification of Statistics*) are not simply analogous, but identical among bees, ants, or men, and are sometimes more differentiated in the former, sometimes in the latter. Just as the operations of heredity upon man and other organisms are not merely analogous but identical, so also are those of function. Division of labour has specialised the polymorphic castes of the ant-hill; so the same specialisation of function acts towards developing similar polymorphic changes among men.

Every one is more or less conscious of this: it is never difficult to distinguish a soldier from a joiner, or a ploughman from a weaver; while the physician reaches almost incredible skill in eading the finer results of occupation on bodily structures, normal and pathological alike.

The biological reader may well wonder at the insistance upon what is to him a commonplace; but, like so many of the scientific commonplaces enlarged upon in the present analysis, it has been ignored by the vast majority of economic writers. It does not come within the study of processes of production on one hand, nor within that of social aggregates on the other; the occupations of ploughman and weaver or joiner are alike productive—are all equal in the eye of the politician and before the law. To economists, whose preparatory studies included no biology, any insistance upon the wide difference of these occupations to the men performing them must needs seem mere nonsense, and the proposal to found practical action upon the observed results pure "sentiment." But, without the slightest postulation of morals, it is a biological fact that, as "function makes the organ," it also shapes the organism, and modifies it either for evolution or for degeneration; moreover, other things equal, determines its quantity of health and limits its length of life. Ploughmen and weavers, joiners or soldiers, then, are incipient castes, as surely as Brahmin and Pariah, queen, worker, and drone, are formed ones; and the disadvantages of the division of labour, so slowly forced into prominence (as, little to the credit of biologists, they have been) through the sufferings of the many and the moral enthusiasm of an unscientific few, demand study and classification among the "Variations of Animals and Plants under Domestication."

§ 32. *Modification by Environment.*—Even when we study the ancestral environment separately as heredity, and the functional environment or occupation separately as function, besides leaving the social environment for a subsequent discussion, there remains a series of influences, those of the ordinary environment, which probably exceed any others in importance. Food, which alone determines whether the young bee is to be worker or queen, has a thoroughly well-marked influence upon men. The importance of the quality of the atmosphere is becoming recognised. So also with light: the gardener blanches his celery, the zoologist stops the development of the tadpole by withdrawing light, the sphygmograph shows how the pulse bounds at every gleam of sunshine, and the physiologist and physician are not hesitating to generalise and apply these results to the development of human life in towns.

It has been assumed by most economists that the "necessities of life" were simply food, shelter, &c., and that the subtler factors of the environment need not be included. This pre-biological conception need not be argued with, for the economic problem of the maintenance of men is but one special case of the vast problem of the modification of organism by environment, exactly as the descent of man is a special case of the origin of species.

§ 33. *Mode of Modification of Organism by Environment.*—Although time and space and knowledge do not admit of tracing out these lines of modification in detail, some idea of the two main lines of evolution and degeneration respectively must be obtained. It is convenient to begin with the latter, since the conditions of degeneration in the organic world are approximately known. These conditions of degeneration are of two very distinct kinds—on the one hand, deprivation of food, light, &c., so leading to imperfect nutrition and innervation; on the other, a life of repose, with abundant supply of food and decreased exposure to the dangers of the environment. It is noteworthy that while the former only depresses, or at most extinguishes, the specific type, the latter, through that disuse of nervous and other structures, &c., which such simplification of life involves, brings about that far more insidious and thorough degeneration seen in the life history of myriads of parasites. It is noteworthy that both these sets of conditions of organic change exist abundantly in society, the former being known as poverty, the latter as "complete material well-being." The influence of all this upon the degeneration of individuals and upon the decline and fall of nations alike, need not be insisted upon.

Passing now to the less known conditions of evolution as opposed to degeneration, it is obvious that (1) adequate conditions of food, light, atmosphere, are necessary; (2) that the organism, and primarily the nervous system, must be adapted to more and more complex conditions of the environment; *i.e.*, that the nervous system must become more and more highly evolved.

Hence arises the physiological explanation of the æsthetic sub-function in production, of which we were compelled to notice the enormous importance even under the preceding analysis of physical principles. It is determined by the need of the various senses, and

the cry for so-called "utility" in ultimate products is frequently nothing more than a demand for the lower forms of æsthesis in preference to the higher.

§ 34. *Definition of Production.*—No definition of production is possible from the physical point of view alone, since it involves a knowledge of the organism to which production is adapted. Now, however, production is definable in general terms as the adaptation of the environment to human functions; and every productive action thus tends either towards maintenance and evolution or the reverse. This simple idea is not yet, however, sufficiently active in our industrial age. The functions of production are undertaken by industrialists, chiefs and proletaires alike, mainly with the notion of obtaining "wealth" in its very variable proportions of maintenance, power over others, personal immunity from function, &c., a conception of the nature and aim of production upon which our surviving industrial anarchy mainly depends. The adaptation of the world to the wants of the species, which we see to be the beginning and end of production, is again definable in biological language as the substitution of human for natural selection.

§ 35. *Polymorphism and Competition.*—We have already seen how, in the evolution of production, specialisation of function in a community of organisms was attended by polymorphism—the resultant structural specialisation. This polymorphism has a most important bearing on the economy of the community. In a little differentiated community, competition is at its highest pitch; in a polymorphic one, it is reduced almost to zero. In a hydractinia or siphonophore colony, in an ant-hill or bee-hive, competition is minimised. Struggle for existence between the members has ceased, the only struggle is with other communities. So far, then, is competition from being the sole idea derivable by economics from biology, as is so commonly supposed, that in fact competition is ever in inverse ratio to polymorphism; and in a given community polymorphism puts an end to internal, though not necessarily of course to intersocial, struggle. Internal competition can only be intense in large communities where there is but little polymorphism.

§ 36. *Production and Reproduction.*—We have seen that for the elaboration of ultimate products machines and automata are necessary. Increase of production, therefore, involves increase of machines and

of automata—of both in so far as they are not interchangeable. This increase of animal automata (given that supply of transitory ultimate products known as the standard of comfort) is attained by reproduction, and increase of a given class of population is therefore determined by the amount of the transitory ultimate products supplied—and hence by the "capital invested" in that industry. Increase of permanent products, on the other hand, does not tend to increase the population. The reproductive ratio of any class of producers per unit time is thus a fixed and definite one, and approximately ascertainable. (*Cf.* Appendix to Chap. I. § 28.)

The multiplication or decrease of any class of the community is, in short, strictly comparable to the hypertrophy or atrophy of the cells of an organ in proportion to its functional activity and nutritive supply. (*Cf.* article "REPRODUCTION"—*Encyclopædia Britannica.*)

Appendix to Chapter II.—Practical Biological Economics.

§ 37. *Practical Biological Economics.*—As in the case of physical economics, so here we have two alternative practical ideals:

1. To maximise the maintenance and evolution of the community.
2. Or to minimise the same.

All action is referable to either of these categories, and tends necessarily in one of those directions. As practical economists, we are shut up to the selection of the first, and we have only to consider how this ideal can best be realised. This involves a criticism of life from a biological standpoint; a subject analysable into endless detail, *e.g.*, the criticism of production alone embracing processes so apparently remote as food-analysis and art-criticism. The details of such a discussion cannot be given here, but the lines to be followed may be indicated. The modifications of the organism must be determined and analysed into their various factors, viz., (1) the effects of organism on organism in heredity (education and competition); (2) the influence of function on the organism towards degeneration on the one hand, and towards evolution on the other; (3) the modification of the organism by its material environment, such as food, dwelling, air, light, &c. Not only must these factors

in modification be observed and appreciated, but their modifiability must be discussed and acted upon. Thus, in the case, when any given environment or function, however apparently "productive," is really fraught with disastrous influence to the organism, its modification must be attempted, or, failing that, its abandonment faced.

After a thorough analysis of this sort we can attempt the treatment of such practical questions as the state of the poor, or the advancement of social progress in general—since practical action, at present dispersed into special efforts, each dealing with some aspect of organism, function, or environment alone (or of some mixture of these), must on pain of failure attempt the synthetic treatment of all.*

It only remains to be pointed out that the ideals of human selection which are beginning to be suggested on all hands, as biological conceptions penetrate modern thought, are to be worked out on one economic basis, that of adapting production to organism.

Chapter III.—Psychological Principles.

This department of the subject, unlike the two preceding, has an extensive literature, of which it is necessary to examine the main positions at the outset.

§ 38. *Pleasure and Pain.*—A psychological basis for economics has often been sought in the theory of pleasure and pain—in the conception that we should find at once a theory of observed actions and a basis for expedient action in the pleasure or pain observed to attend them. Without disputing the possible high importance of this standpoint, or insisting too much upon the impossibility of verifying the measurements of pleasure and pain which Mr Jevons and Mr Edgeworth especially have used so freely, it must be pointed out that it is far from furnishing an absolute criterion. According to Spencer, "pain is correlative of actions injurious to the organism, and pleasure of those which are advantageous." But a

* *I.e.*, all beneficent or benevolent agencies whatever thus fall into three genera, or rather brigades (*e.g.*, ecclesiastical, charitable, educational, medical, &c., into the first; trades-unions, &c., into the second; associations concerned with hygiene, housing, art, &c., into the third). This classification, moreover, corresponds to the developmental succession of such agencies; and this is now approaching an end, while the requisite co-ordination is becoming possible.

qualification is necessary—since pain is correlative of new adaptations, pleasure of old and familiar ones, which lead through economy of material to degeneration—not improbably one of the most pleasurable of organic processes. This theory, then, will need considerable emendation before being serviceable as a basis for economics.

§ 39. *Conception of Value.*—One of the latest and most nearly satisfactory analyses of the much-disputed and ambiguous term "value" is that of Jevons,* who resolves it into three distinct factors:—"(1) Value in use, or *total utility*; (2) esteem, or urgency of desire for more, or *final degree of utility*; (3) purchasing power, or '*ratio of exchange*.'" Again, according to Walker, a commodity possesses "value when it is an object of man's desire, and can be obtained only by man's efforts;" while Bastiat explains that "value does not reside in the commodities themselves, and is no more to be found in a loaf of bread than in a diamond, the water, or the air." And such definitions and explanations are repeated indefinitely in other works.

But in terms of the present analysis it is evident that the "value" of anything has a significance varying with the standpoint of each successive science,—that "ratio of exchange" expresses an essentially mathematical aspect, "utility or intrinsic value" its physical or physiological sense, "intensity of desire" its psychological, and "purchasing power" its sociological aspect. The long disputes respecting the nature of value are thus clearly analogous to the famous case of the gold and silver shield. From the psychological standpoint, for instance, the conception of intrinsic value is clearly irrelevant; and to economists of conventional academic training, acquainted with the current logic and metaphysics, but without a suspicion of physical and biological facts, the exclusion of every other point of view necessarily followed. From this point of view, especially when we bear in mind the idealistic philosophy of the schools, the dogma of Bastiat is a commonplace, and the thoughtless copying of it by equally pre-scientific writers is natural; it has, however, no more interest to the economist than any other platitude of idealism: the facts for him being, as was above pointed out—(1) that loaf and diamond are observed to exchange in a certain ratio (mathematical value); (2) that they possess a certain number of

* *Math. Theory of Pol. Econ.*

units of potential energy as combustible (physical value); (3) that the former is capable of maintaining an average adult for a definite time, while the latter possesses a definite power of sensory stimulus (physiological value); (4) that corresponding to the preceding physiological functions are their subjective aspect, known as wants or desires (psychological value); (5) that, as property, they acquire a sociological "value," which cannot as yet be entered upon.

The idealistic position, though extremely popular, has never been consistently maintained; the reverse position is often tacitly taken, as apparently in the dogma that "labour is a commodity," and the like.

The attempt then to base the psychology of economics upon the aspects of *value*, and much more to make it the centre of the whole science, turns out futile; so far from being fundamental, it is in fact almost superfluous, since it is either the subjective expression of an actual objective value (physical, biological, or sociological), or an erroneous hypothetical estimate of one or more of these.

§ 40. *Wants and Desires.*—Can "wants and desires," however, be taken as completely expressing the psychology of action? Probably not completely, since there is much ground for suspecting that complex associations never formulated in consciousness play an important part; perhaps, too, that even lower states of cerebral activity have their share in determining action.

Let us see, however, how the conception is developed by economists. Their current positions may most fairly be stated by quotations from well-known authors. "Political economy teaches the relation of man to those objects of his desire which he can obtain only by his efforts" (Walker, *Science of Wealth*, p. 2). "The objects or satisfactions obtained by these efforts are collectively called wealth." Again, "wealth is whatever satisfies a desire or serves a purpose." Again, according to J. B. Say, "that society is most civilised which produces most and consumes most;" or, in other words, which has the greatest quantity of artificial wants. From the preceding it follows—(1) that all wants and desires are equally valid in the eyes of the economist, who can make no other criticism of wealth; (2) that the only recognisable progress lies in differentiation, and in this most economists fully concur.

Despite the importance attached to wants and desires, they have

rarely obtained any detailed analysis or classification whatever. The most recent and elaborate attempt is probably that of Syme (*Industrial Science*, p. 106). He divides them into (I.) *Egoistic*, or wants and desires for food, drink, rest, &c.; (II.) *Hemeistic*, having for their object the gratification of the social emotions, such as affection, esteem, love, hate, &c.; (III.) *Allostic*, having reference to actions, and having for their object justice.

In the vast majority of works, however, no such analysis is attempted; some generalisation of these varied wants and desires is, however, needed; this is obtained by boldly uniting them under the term self-interest or egoism—this done, it is evident that self-interest is the mainspring of all economic action, and the basis of orthodox economics is complete. A principle capable of endless deductive applications is obtained, and if any unbelief as to the exhaustiveness of the generalisation arises, the wide prevalence of egoism in the individual and in the community is readily appealed to, and the sceptic held up to derision as a sentimentalist. With all respect, however, to these systems, a new analysis leading to somewhat different conclusions must now be briefly attempted.

§ 41. *Statement of Psychological Principles.*—In discussing the biological principles of economics, we considered men as organisms (*a*) having certain functions applicable to the maintenance and evolution of self and others, or to the contrary; and (*b*) with certain wants, *i.e.*, requiring certain adaptations to the environment, again either in the direction of evolution or of degeneration. We find psychological principles parallel to these. Man is characterised by the enormous specialisation of his nervous system, and psychology though in the past mainly restricted to an imaginary account of an independent entity, of mind "as a thinking being *in vacuo*," really deals with the subjective side of the functional aspects of the nervous system. Behind the muscular contractions by which all economic action productive or consumptive alike are performed, are cerebral stimuli inspiring these, and these subjectively considered are wants and desires. The fundamental nature of the subject is therefore obvious. As Walker expresses it, "the central force is the wants of man." That however the wants determining production, &c., are not simple appetites for food, shelter, and the like, is evident when we remember how in the majority of products the

æsthetic sub-function preponderates over that which would merely satisfy the nutritive appetite.

That desires realise themselves in efforts, and that efforts attain satisfaction, is the psychological or subjective side of the objective fact that wants necessitate labour, and that labour results in wealth. A simple economic action—say an amœba devouring a grain of starch, or a labourer consuming food, may be expressed in three ways—(1) physical, the potential energy of the body is increased; (2) biological, the organism is nourished; (3) psychological, a desire is satisfied.

In the very simplest forms of life we find two essential forms of vital action—the nutritive and the reproductive. But Leconte has pointed out that, while the satisfaction of nutritive wants is fundamentally egoistic, the reproductive desire contains the earliest germ of altruism. If this be admitted, as it must be, the exclusion of the altruistic element as a determinant of economic action is at once seen to be a mere artifice, alike impossible and absurd, if our psychology is to have any relation to living beings; while the deductively constructed fabric of orthodox economics collapses without criticism, since one half of its foundation ("self-interest") alone was laid. Starting, then, from this primal manifestation of egoistic and altruistic desires, we may briefly follow the development of these with the ever-increasing structural and social complexity of the organisms. With limited supply and space, these nutritive wants and desires must result in competition between the individuals. Competition has, of course, its objective and subjective aspects; the objective antagonism must be represented by a subjective egoism and mutual antipathy. But every aggregate which can at all be termed a society has risen to some measure of complexity—of division of labour or polymorphism; and even these economists who insist most upon "self-interest" are not wanting in clear explanation of the economic advantage of the process. The subjective aspect of the process is not, however, personal egoism and mutual antipathy; since, for the co-ordinated muscular actions which any increase of polymorphism and synergy imply, a corresponding measure of co-ordination of nervous action is indispensable; and thus, as competition involved *antipathy*, so objective co-operation involves subjective *sympathy*. As mutual antipathy implies individual egoism, so sympathy implies

a measure of altruism. Higher and higher differentiation of social structure and function involves corresponding subjective adaptation; as the economic duties of an individual develop in complexity and remoteness to the immediate result, so must their subjective aspect on pain of failure deepen and widen; and thus the material evolution demands a moral evolution running parallel to it. That the material evolution has for the time outrun the moral adaptation is, in fact, from the present point of view, the essential explanation of much existing economic anarchy.

As the society reaches completer polymorphism, altruism increases; progress towards the physical and biological ideal of productive synergy involves parallel progress to an ideal of sympathy or maximum altruism. This does not, however, at once extend to different societies; between these competition and antipathy may exist to any extent; but as antagonism becomes subordinated to community of interests, here also antipathy becomes replaced by sympathy.

The concomitant parallel progress of reproductive action—incident upon the origin of the family and the progressive integration of families into higher and higher aggregates—is too familiar to need recapitulation here. It is evident that even on the most sternly biological grounds, so far from a scientific basis for economic deduction being furnished by "the iron law of competition," the highest generalisation of the phenomena (from which deduction, if anywhere is alone permissible) is the accurate converse of this—the golden rule of sympathy and synergy. And it is a remarkable result that, without introducing into the argument any so-called moral or sentimental considerations, but arguing soberly from the two fundamental functions and wants of living beings—from nutrition and reproduction alone—the noblest ideals of politics and morals arise before us.

Appendix to Chapter III.—Practical Psychological Economics.

§ 42. Can our psychological conceptions of (1) pleasure and pain, (2) value, (3) of wants and desires, furnish a basis of economic action? Actions may be classified as they produce pleasure or pain, or as they tend to satisfy our desires; but such an attempt, however reasonable in constructing a theory of personal action,

has never been successfully applied to social action. Nor is it adequate even in the simplest case. Taking the amœba and labourer of the preceding illustration, both frequently satisfy desire by the consumption of that which is not food in the biological sense, and of what supplies no energy from the physical. Here then a dilemma arises: if with the majority of economists we recognise no physical or biological aspects in the phenomena of economics, all wants and desires are alike expedient, since no criterion of action exists, and *laissez faire* becomes the only practical maxim. If, however, we recognise physical and biological facts, and the psychological as the subjective aspect of the latter, then the psychological economist must simply commend those wants and desires which are conducive to maintenance and evolution, and these only.

"It is not enough to transfer the point of view from the individual to the race, and to take the social factor into account; we must also frankly accept the biological point of view, which, regarding mental functions as vital functions, and states of consciousness as separable from states of the organism only in our mode of apprehending them, sets aside the traditional conception of mind as an agent apart from the organism." *

From this sharply defined statement of the position of the present chapter (*cf.* Introduction, § 13), we are thus forced to draw the following economic corollaries:—(1) Since, from the physiological side, the nature, amount, and direction of muscular activities are dominated by cerebral action, the cerebral functions are supreme; (2) as similarly, from the psychological side, all functions are equally—nay, are solely—expressible as cerebral, the functions of creative and directive thought, the activities of education, &c., are as really "productive" as any. Thus our economic utilitarianism passes from the crudely practical state to that into which it has been recast by its more philosophical exponents; and if psychology, leaving its academic isolation, assumes its modern position, schoolmaster, hodman, and artist, are alike productive. The problem of practical economics now demands that we produce not that mere maximum of food and eaters, which is the first aspect of the physical ideal; not even that perfection of

* Lewes, *Study of Psychology*, chap. i.

quality and quantity of physical life which is the first aspect of the biological; but the maximum evolution of mental and moral nature which underlies the two former. The problem, in fact, inverts itself, becoming not merely how to fill bellies, but how to place brains in the conditions most favourable to their development and activity, and so the problem of practical psychological economics passes into that of education. The supremacy of the æsthetic factor in production, demonstrated under "Physical Principles," is thus explained :—The modification of the environment which is the object of production, while primarily addressing the nutritive system and attending to protective needs, must culminate in that complex organisation of the environment which, deliberately addressing itself to the stimulus and evolution of the sensory activities, is of such importance for the process of cerebral evolution (a wealth of impressions being the indispensable raw material of the most complex or highly generalised intellectual conceptions), and which we therefore term *fine art*.

Summary of Chapters I.–III.

§ 43. At this point it is convenient to pause and briefly review the results of these analyses. Passing over the criticism of economic literature, (1) the physical analysis led to the exposition of the mechanical aspect of society; to the reorganisation of the theory of production and consumption, culminating in the generalisation of the synergy of the race. (2) The biological chapter outlined the higher aspect of the same phenomena, defined production, &c., and discussed the relation of organism to the environment and function—a definition of production being obtained in terms of maintenance and evolution. (3) A psychological outline in harmony with the present state of science was attempted; and many subjects not usually treated under economics were seen to form an integral part of the subject. Yet this is by no means sufficient; a sociological analysis is wanting; and the whole series of analyses are but materials for a subsequent synthesis. But a pause may reasonably be made before entering on this, and a clear gain has been made if these results are plain (*a*) that the analysis of so-called systems of political economy is neces-

sary and possible, and that on the present lines; (*b*) that the analysis does yield many results of clear principle and practical application; and (*c*) most important of all, that many of the most burning questions between producer and consumer, worker and capitalist, individualist and socialist, utilitarian and sentimentalist, are soluble on the field of pure science without appeal to sociological or political methods at all.*

To the present scheme numerous objections are constantly proposed, and these, so far as the writer is aware, may be analysed and grouped as follows:—It is said (1) that the present survey is too wide, that it discusses principles which are not relevant within the proper sphere of economics; (2) it seems difficult to make sure of the actual logical sequence of the argument, and (3) to see its applicability to details; or (4) there arises a suspicion of the insidious postulation at some early stage of the argument of the ethical considerations which appear as results; or (5), and most commonly, the results seem too good to be true.

To which it may be replied, that (1) hardly any matters are introduced which will not be found, in chaotic form indeed, in the standard works on economics, and that the usual restrictions of the subject to one particular division of the subject (*e.g.*, to the theory of production and consumption apart from the relation of these to the organisms), are arbitrary, and proceed usually from ignorance or misconception of the subjects excluded; and moreover that, even if it may still be thought by some to be too wide in its scope, it is yet a continuous train of reasoning connecting the widest generalisation of knowledge (the classified sciences) on the one hand, with the minutest details of technology or consumption on the other; while most so-called systems have been set afloat either without cargo of fact or compass of science; (2) that the present channel of publication is the most direct method known to the writer of challenging and obtaining a keen scientific scrutiny; (3) that the indispensable and yet less pressing question of its application to detail, although excluded because of limits of space, &c., can not only be tested by any one who cares fairly to master the general

* Thus the dispute preceding the passing of the Factory Acts did not lie between "economic science" and "sentiment," but between the ideals of physical and biological economics (*q.v.*).

principles, but is at least to a very great extent vouched for by the mode of construction (not only synthetic and deductive, but analytic and inductive throughout, and embodying the generalisation of long preliminary studies of economic detail) (see *Classification of Statistics*, p. 19). This difficulty can be best got over by reading these essays side by side with such a vast storehouse of facts as the well-known manual of Roscher; though the reader may be once more and finally reminded that he must not expect to find in these rough draughts for the ground plans of successive stories of the economic edifice, the completeness and detail, the colour and perspective of the projected whole. (4) The suspicion of the premature postulation of ethical considerations, if present, is due to the reader's discovering more or less clearly for himself that ethics is not an isolated science, but a generalisation of the acts or practice corresponding to each of the orders of scientific considerations, physical and biological, &c., and that the ideals of maximum production and maximum evolution respectively were as much the ethic of physical and biological considerations as that of sympathy is that of psychological ones. The fifth objection, due to discouragement from previous failures to find a synthesis, need not of course be argued with.

But the real difficulty of the paper lies in its inevitable and extreme compression, and its consequently generalised form—the requisite application of the principles to the familiar details of economics, and their exposition in more literary form, being alike only suggested in an occasional sentence. The essential aim will, however, have been attained if it has been adequately demonstrated (1) to scientific specialists—physicists, biologists, or psychologists alike—that each respective aspect of economics lies fairly within their range, and (2) to professed economists, that such a mode of reinvestigation is not only practicable, but expedient.

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